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AMFC: A New Approach Efficient Junctions Detect via Maximum Flow Approach

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Abstract
In this study, max flow analysis processes are carried out with a graph theory-based approach that can be used in optimizing the traffic load in transportation networks. The data used in the study consists of 2 years of vehicle number data consisting of 438 million vehicle passes of a real city. Bottleneck points affecting traffic flow, maximum flow values, and effectiveness values of traffic generating and attracting locations were determined in the uniquely created transportation network. The Ford-Fulkerson algorithm was used to determine the maximum flow and bottleneck road connections in the designed transportation network. According to the maximum traffic flow to the junction point, the most effective junction points were determined by the PageRank algorithm. In addition, a unique algorithm is presented in the study that determines the effective intersection points that transfer vehicle traffic at maximum capacity to all junction points according to the maximum demand capacity data. The analysis results produced by the proposed method constitute an important decision support system for traffic management and transportation network design.

1. Introduction

One of the most important factors in making a city livable is a developed and sustainable transportation system [1]. The transportation network must be manageable and developable for this sustainable structure to continue. The measurability and manageability of the transportation network depend on converting the traffic data into digital form and processing it with data mining techniques. In this way, determining the vehicle carrying capacity of the roads and junction points, which constitute the important parts of the transportation networks, enables many different optimization processes to be performed on the urban transportation system [2]. Studies in the literature show that transportation networks modeled based on graph theory give very successful results [3, 4]. Calculating the maximum vehicle traffic at determined locations in transportation systems is a significant problem. In computer science, this type of problem is solved with the max flow approach. The determination of max flow is expressed as an NP-Complete problem that cannot be solved in polynomial time [5]. The max flow approach calculates all flow values between the two specified locations and detects the connections with the weakest flow despite the maximum flow potential in the network. The places with the weakest flow are called bottleneck points [6]. In this study, the transportation network in the city was designed by using the real vehicle count data of a city. This weighted graph is used to determine the transportation network's bottleneck points and the most effective intersection point under the maximum flow. In addition, with the proposed Average Maximum Flow Closeness (AMFC) algorithm, the efficiency of the points producing vehicle traffic according to the maximum demand capacity has been determined.

2. Related Work

There are studies in the literature that use various approaches to determine maximum flow values and bottleneck points. The maximum flow approach,

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which is very popular in transportation, has often been used to balance and optimize the traffic load [7]. Studies on the determination of the maximum flow value in the transportation network [8] and the determination of the speed ratios [9] at which maximum safe flow will be provided have provided significant benefits. In particular, maximum flow calculations were carried out for the optimization of green light flashing times in signaling systems, which is one of the important criteria affecting the management of the transportation network [10]. In addition, there are effective methods developed to detect bottleneck points that will cause interruptions in the transportation network [11, 12]. By designing transportation networks of real cities, analyses such as determining the bottleneck points and determining air pollution with travel speed data [13], bottleneck cost [14], and PMFA [15] were carried out. Maximum flow is used to highlight the importance of bottlenecks in high-scale networks [16] and to correlate traffic carrying capacity with signal timing parameters [17]. Maximum flow approaches have a very wide area of use outside of transportation networks. By determining the capacity flexibility of the passenger transportation network, it is possible for individuals to have route selection [18]. In power networks, critical capacity values have been determined for each situation where the network is resistant to failures [19]. Ford Fulkerson method has been applied to determine the maximum electrical carrying capacity in electrical transmission lines [20]. In another study, it is aimed to determine the maximum production rate that the network can reach when a production flow network with known edge capacity is given [21]. To support flow latency control in TDMA-based wireless networks, a flexible bandwidth allocation and uncoordinated scheduling scheme called two-stage link scheduling (2SLS) [22] have been proposed. The fragility analysis of the carrying capacity of the natural gas pipeline network [23] is carried out, and the capacity differences are explained from the perspective of graph theory [24].

When the studies in the field of transportation are examined, it is seen that the data sets used in most studies are limited or randomly generated. In this study, an important analysis of traffic flow has been carried out by using vehicle count data from a real city. The data used consists of vehicle count data passing through 161 road connections connected to 41 junction points. The dataset, which includes 438 million vehicle passes, consists of 2-year vehicle count data. The data consisting of approximately 56 million rows of SQL data was filtered and transformed into 1-hour count data. The transportation network graph is weighted according to the maximum number of vehicles obtained (Realized Demand capacity). The dataset specially prepared for this study makes the study unique in this respect. Maximum traffic flow values and bottleneck points were determined between the locations determined according to the scenarios created in line with the needs of the city. Ford-Fulkerson algorithm has been applied to determine the network's maximum flow and bottleneck edges. In the study, the most efficient junction points were determined according to the incoming traffic load by using the PageRank algorithm. Furthermore, a unique method for determining the effectiveness values of traffic-generating points that are thought to contribute to the literature has been proposed. The proposed AMFC algorithm evaluates the transfer potential of the traffic load arriving at the intersection at maximum capacity and determines the efficiency values of the intersection points accordingly. Important outputs were obtained by applying the AMFC algorithm on real field data. This way, the order of importance of the traffic-generating locations has been determined and explained comparatively. Another feature that distinguishes the study is that the road's vehicle carrying capacity is not physically used while the transportation network is weighted. Instead, the transportation network was weighted by determining the maximum demand values based on traffic flow in 1-hour periods over a city's two-year period. The fact that the data set is inclusive of the city and consists of big detailed data has increased the success and quality of the employee.

3. Material and Method

The development process of the study is explained in 5 primary stages with the graphical summary given in Figure 1. In Stage 1, the junction and road relations of the city to be analyzed (Malatya city in Turkey) were determined, and the transportation network graph was designed. The generated transportation network graph has 41 junction points and 161 road connections. In Stage 2, vehicle count data consisting of approximately 56 million rows of SQL data, (The data consists of time, green time, vehicle count, direction and junction columns), belonging to 161 roads taken from the city's signaling system was processed through data preprocessing processes. The vehicle count data used covers a period of 24 months. During this period, approximately 438 million vehicles passed through the designed transportation network. In Stage 3, the vehicle count data of 24 months were grouped at 1-hour intervals, and the vehicle count data at the peak point was determined. This process was carried out separately for 161 different road connections. In Stage 4, the entire transportation network is weighted with the peak pass data. This way, the transportation network is weighted with the road's realized maximum capacities by using the maximum demand value according to the real traffic data. In Stage 5, three important analyses were carried out, namely maximum flow, bottleneck location detection, and node efficiency, using the transportation network designed using the original data set. In the next stage of the study, extra explanations about these summarized stages are given. In this study, MS SQL Server was used for vehicle count data preprocessing, and R programming language was used for the development and implementation of algorithms. In addition, the igraph and visnetwork libraries were used to visualize and perform graph-based operations on the transportation network.

Figure 2 zooms in on a sample area in the red square and provides a visual representation of transforming signalized junction points into a graph. The green circles in the image represent the junction points, and the blue lines represent the road connections connecting the junction points.

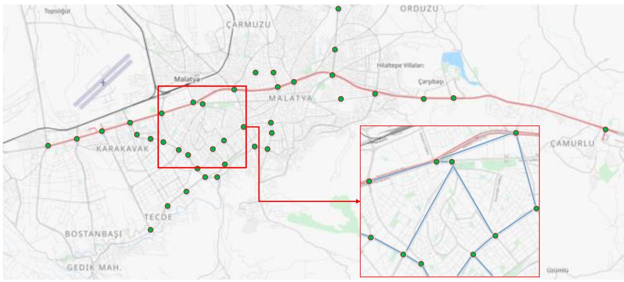

Figure 2. The designed transportation network graph.

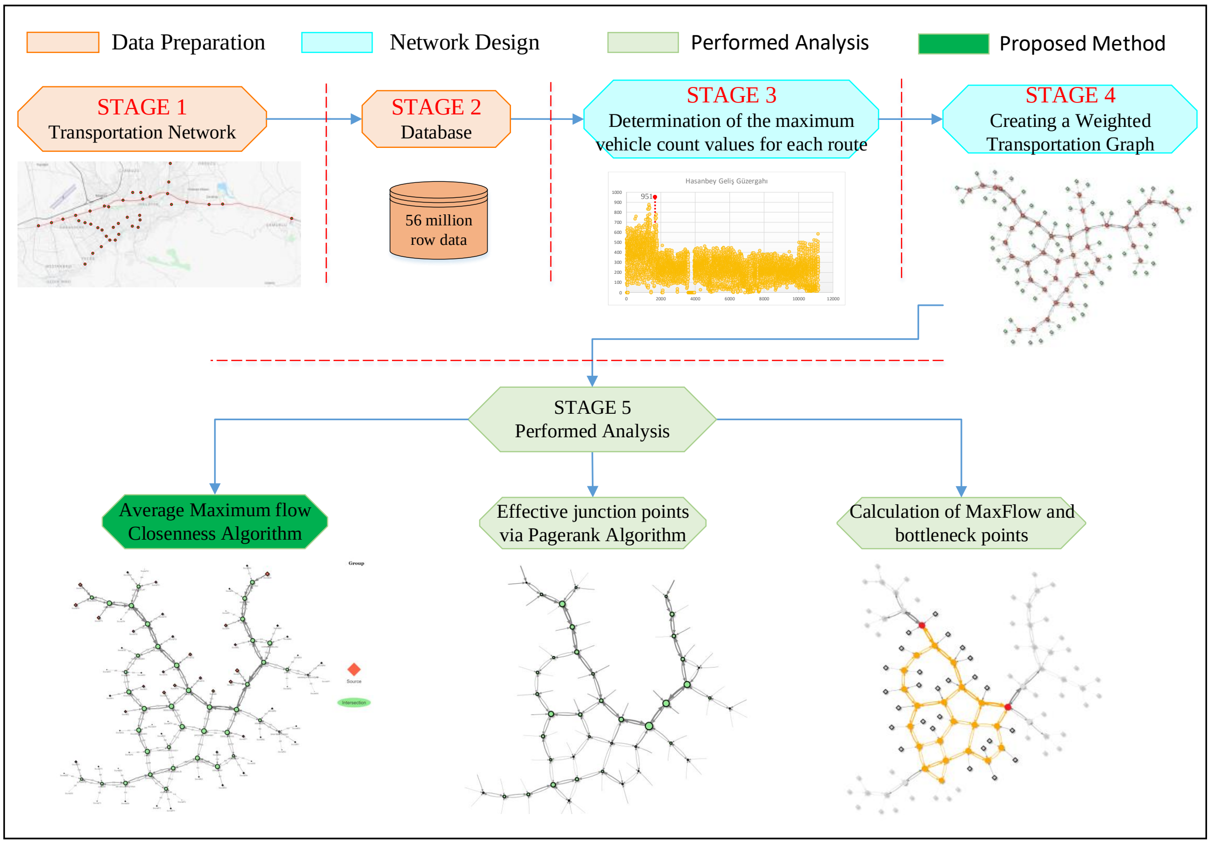

Figure 1. Analysis process

Let's explain how road connections are weighted for an example intersection in Figure 3. Figure 3 shows the weighting of 4 different roads connected to the Temelli junction point. These roads are Mezarlık Geliş, Feyzullah Taşkınsoy, Dede Korkut, and Hasanbey arrival routes. When the Dede Korkut arrival route is examined, the vehicle count data in 2 years, approximately 11,500 different (1-hour intervals) time zones, can be seen. Each yellow dot in the graph represents the vehicle count data in the 1-hour interval. The maximum number of vehicles in the Dede Korkut Geliş direction within these time zones was 1277 (peak point). Each point on the yellow graph is the vehicle count data in the 1-hour interval. As indicated in the graph, the road edge related to the 1277 value at the peak point has been

weighted. The process performed is indicated on Figure 3 with a red arrow.
Like the Temelli arrival, direction operation was carried out for all 161 road connections in the transportation network. And all the edges of the transportation network are weighted. Figure 4 gives the visual for the final weighted transportation network diagram. While the red nodes in the image represent the source points (traffic-generating nodes), the green circular nodes indicate the junction points where the roads intersect. The edges expressing the roads are sized according to the vehicle count data. Edges with a high vehicle count are thicker, while edges with a low vehicle count are thinner. The area indicated by the red borders on the image is given in a zoomed form.

The most basic step of the analysis process is determining the maximum flow values in the network. The maximum flow value represents the vehicle traffic capacity that the transportation network will carry between 2 different locations [25]. Maximum flow is one of the fundamental parameters in this study's analysis. Ford-Fulkerson algorithm was used to detect bottleneck points(Maximum Flow) in the network. Considering the maximum vehicle crossing densities, the most effective junction points were determined according to the vehicle traffic coming to the junction points with the PageRank algorithm. One of the original outputs of the study is to determine the efficiency value of traffic-generating points.

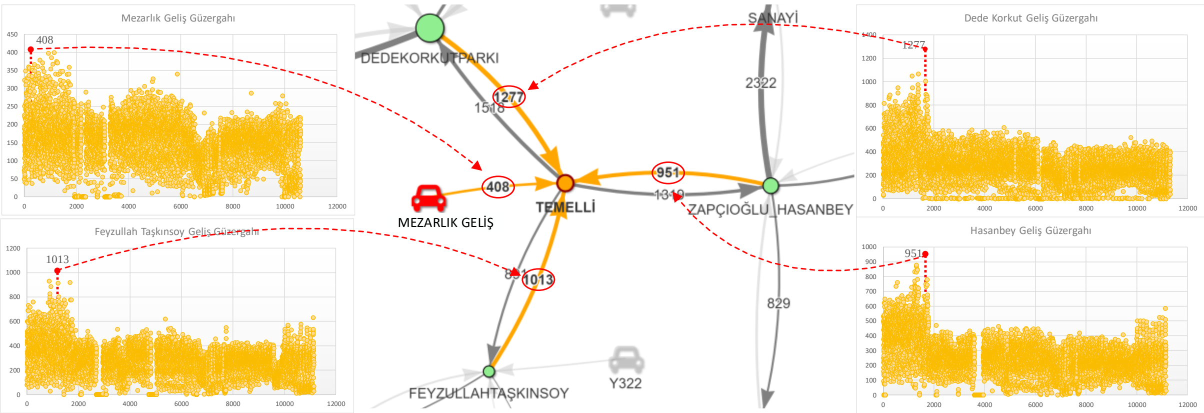

Figure 3. The weighting of the transport network

This original proposed method is named the Average Maximum Flow Closeness Algorithm (AMFC). The method's main goal is to determine the potential of the points that generate vehicle traffic to distribute the traffic they generate to the entire network. The proposed algorithm includes the maximum flow approach and the approach of reaching the nodes of the closeness centricity algorithm. The following sections provide detailed information about the methods used and developed during the analysis process.

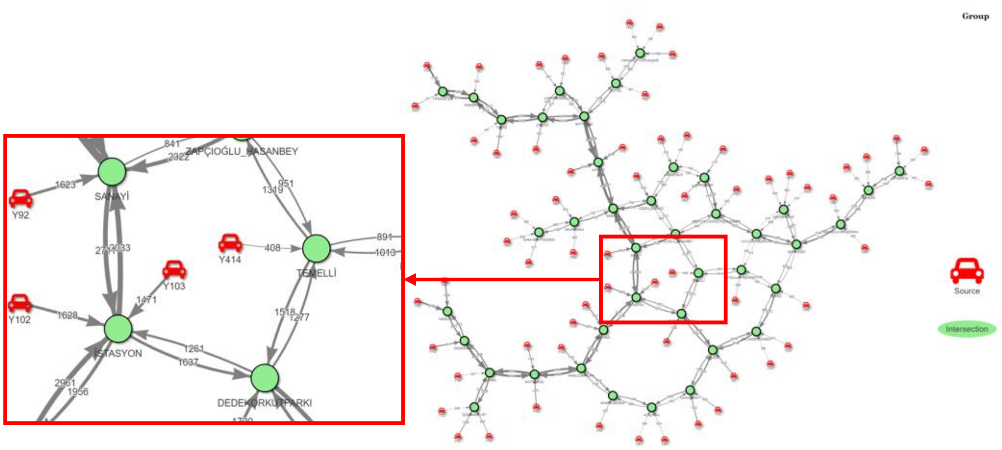

Figure 4. Transportation network weighted with maximum flow values

3.1. Maximum Flow

The purpose of the maximum flow problem is to find the maximum flow from a single source to a single sink in a given flow network [26]. This problem is defined in graph theory as the NP-Complete problem type that cannot be solved in polynomial time [27]. In Figure 5, the vertex labeled S represents the source point, and the vertex labeled T represents the target point or sink point. The edge weights on the graph give the capacity information of the relevant edge points. As understood from the graph, the graph given is a directional graph. The indicated directions represent the direction of the flow in the graph. In order to find the maximum amount to be transferred from the S node to the T node in the example graph, it is essential to identify the bottleneck points.

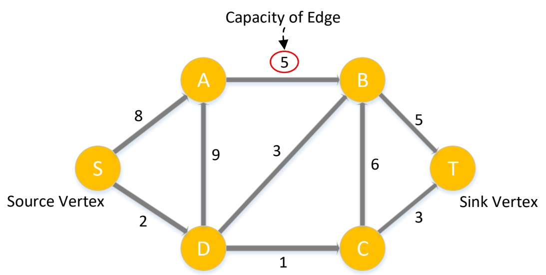

Figure 5. Maximum Flow Network [28].

G = (V, E) is defined as a directed graph. E denotes the edges in the graph, while V denotes the nodes. Each edge e in the flow network has a capacity c_e, which is a non-negative number. The network also consists of a single source node $s \in V$ and a single sink $t \in V$ [29].

For every $e \in E$, $0 \leq f(e) \leq c_e$.

for every node v except s and t, [30]

$$\sum_{e\ into\ v} f(e) = \sum_{e\ out\ of\ v} f(e) \qquad (1)$$

Flow conservation: At each $v \in V\{s,t\}$ node, incoming streams are offset by outgoing streams. That is, all flows through v must be limited, as in equation 1 [31].

$$\left(\sum_{e_n \in N(v)} p(e_n)\right) - p_s(v) + p_t(v) = 0 \qquad (2)$$

In Equation 2, $N(v) \subset E$ is the set of edges connecting v to neighboring nodes. The maximum flow problem tries to find the largest amount of flow allowed from the source.

$$\max_{p_s} \sum_{v \in V\{s,t\}} p_s(v) \qquad (3)$$

As given in Equation 3, when a flow p(e) on edge $e \in E$ reaches the corresponding capacity $C(e)$, it is said to be saturated, otherwise unsaturated [31].

3.2. Ford-Fulkerson algorithm

The Ford-Fulkerson algorithm is a greedy approximation algorithm that calculates the maximum flow value in a flow network. L. R. Ford Jr. and D. R. Fulkerson developed the algorithm in 1956 [32]. The idea behind the algorithm is briefly as follows: As long as there is a path from the source (start node) to the pool (end node), flow is sent along one of the paths with usable capacity on all edges of the path. A path with available capacity is called augmenting path. The formula for the algorithm is given in equation 4 [33].

$$c(V,E) = \sum_{u \in S, u \in T | (u,v) \in E} c(u.v) \qquad (4)$$

$G(V,E)$ is a finitely directional graph. (u,v) denotes the edges, while $c(u,v)$ denotes the capacity value of the relevant edge. Nodes s and t represent the source and sink points, respectively. Cut işlemi S ve T düğümlerinin iki kümeye ayrılma işlemidir. The cut operation is the process of separating S and T nodes into two clusters. Therefore, $2^{|V|-2}$ possible cuts occur on the graph. $c(V,E)$ gives the maximum capacity of interrupts in the graph [33].

In other words, each edge correlation in the network is associated with a positive number called capacity. In this context, the flow amount f_{ij} on one side must meet the condition of not exceeding the flow capacity c_{ij} determined for the edge, as stated in equation 5. This expression is called the capacity constraint or boundary condition. In addition, as given in equation 6, it must be ensured that the inflow (f_{ki}) equals the output (f_{ij}) for every vertex except the s and t nodes. Given these conditions, the algorithm's goal is to maximize the flow between s and t as much as possible [20].

$$0 \leq f_{ij} \leq c_{ij} \ \ (i = 1,2, \dots \dots, n; \ j = 1,2, \dots . . n) \tag{5}$$

$$\sum_k f_{ki} - \sum_j f_{ij} = 0 \begin{cases} f & , if\ i = s \\ -f & , if\ i = t \qquad , i = 2, \dots \dots . , N-1 \\ 0 & , otherwise \end{cases} \tag{6}$$

3.3. Pagerank algorithm

It was developed by Lary Page and Sergey Brin in 1998 [34]. It has been used to prioritize web pages in order to deliver the most suitable web pages on the Internet to users [35]. If we consider the related web pages as nodes, a centrality value is generated according to the importance of the incoming links to the nodes. By means of this centrality value, the priority of displaying web pages in search engines is realized [36]. The formula of the algorithm is given in equation 7.

$$PR(A) = (1 - d) + d\left(\frac{PR(t1)}{C(t1)} + \dots + \frac{PR(tn)}{C(tn)}\right) \tag{7}$$

tn: the relevant source node, PR(tn): the values of the source nodes, C(tn): the number of connections that each node gives to other nodes, d: the dumping factor coefficient [36]. In this study, the PageRank algorithm is used to determine the junction points that can meet the maximum demand.

4. Average Maximum Flow Closeness Algorithm (Proposed Method)

Average Maximum Flow Closeness (AMFC) algorithm has been developed to determine the potential of traffic-generating points (Nodes) to transfer traffic at the maximum rate to the entire transportation network. The average flow values obtained by the AMFC algorithm are a unique method recommended to determine the potential of traffic-generating points in the city. The proposed algorithm realizes the maximum flow value to all nodes in the transportation network, which is weighted with the maximum vehicle count data, in a structure similar to the approach of reaching all nodes of the closeness algorithm. The maximum flow value of a traffic-generating node to the remaining 160 nodes is calculated one by one. The average flow of the calculated maximum flow values for each node is calculated. The maximum flow value to the obtained medium will give information about how high a node can transfer the vehicle traffic load it has produced to the overall network. In the study carried out for all nodes, the nodes that produce the best demand at maximum capacity and distribute it the best are determined. In optimizing the transportation network, successful results have been produced about the efficiency order of junction and source points. The formula of the algorithm is specified in equation 8.

$$\frac{\sum_{V_{S},\ V_S \neq V_i} c(V_i, V_S)}{n}, |\mathrm{V}| = \mathrm{n}, 1 \leq \mathrm{s} \leq \mathrm{n} \tag{8}$$

V_i is the source vertex with the number i. V_s represents the sink node in the graph. $c(V_i, V_s)$ i. th source vertex represents the maximum flow value to the sink vertex in the graph. n is the number of all vertices in the graph. In the given formula, the average maximum flow value of the i.th source point to all vertexes in the graph is calculated. This calculation is performed for all vertexes for analysis of the entire network. The flow diagram and pseudocode of the proposed algorithm are shown in Figure 6 and Table 1.

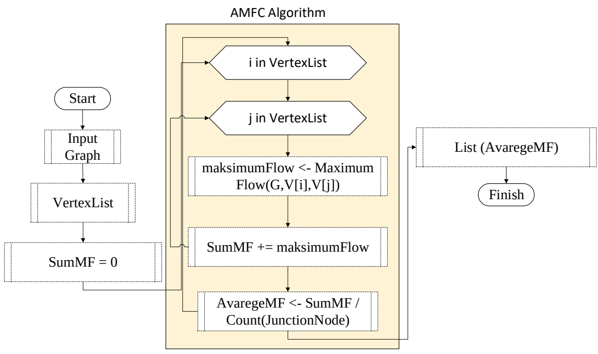

Figure 6. AMFC flowchart

Bottleneck points in transportation networks are an important criterion that directly affects the flow situation in the network. The detection of bottleneck points in the transportation network in certain regions or throughout the network gives important results about the flow. We can express the formation of bottleneck points in 4 stages.

V_i^{in}, It is the vertex that expresses the traffic flow coming to the i junction point in the transportation network. $c(V_i^{in})$, i is the maximum flow amount calculated according to the traffic load arriving at

Table 1. AMFC Pseudocode

Average Maximum flow Closeness Algorithm

```
G:(V,E)
VertexList <- c(V(G))
JunctionNode: Production and attraction points (junctions in the transport network)
u <- Source Node
v <- Sink Node
MaximumFlow(G,u,v){              // Method to detect Max Flow value between Source and Sink
nodes in G graph
flow = 0
for each edge (u, v) in G:
   flow(u, v) = 0
while there is a path, p, from s -> t in residualnetwork G_f:
   residualcapacity(p) = minimum(residualcapacity(u, v) : for (u, v) in p)
   flow +=  residualcapacity(p)
   for each edge (u, v) in p:
      if (u, v) is a forward edge:
         flow(u, v) +=  residualcapacity(p)
      else:
         flow(u, v) -= residualcapacity(p)
return flow }
SumMF <- 0
for (i in VertexList){              // Calculates maximum flow from each node to all nodes
    for(j in VertexList){
       maximumFlow = MaximumFlow(G,VertexList[i],VertexList[j])
       SumMF += maximumFlow    }
    AvarageMaksimumFlow = ToplamMF / Count(JunctionNode)  } // detects the average
maximum flow of the related node to all nodes.
```

the junction. V_j is the neighboring vertex of vertex i. In other words, they are neighboring junction points connected to junction point i. $c(V_j^{out})$ is the maximum vehicle traffic from neighboring junction. k represents the roads coming out of the neighboring junction points.

Theorem 1

Suppose the maximum vehicle traffic arriving at the i junction is higher than the exit traffic volume at the j neighboring junction of the i junction point. In that case, the potenatial of occuring traffic bottleneck problem on the roads connected to i is possible (Eq.9).

$$\sum_{V_i} c(V_i^{in}) - \sum_{V_j \in N(V_i)} \sum_{k=1}^{|N(V_j,k)^{max}|} c(V_j^{out}) \ > 0 \tag{9}$$

Proof: The volume of traffic arriving i junction is $\sum_{V_i} c(V_i^{in})$ and the volume of traffic leaving j junction which is the neighbour of i junction, is $\sum_{V_j \in N(V_i)} \sum_{k=1}^{|N(V_j,k)^{max}|} c(V_j^{out})$. If the difference between volume of arriving traffic and volume of leaving traffic is greater that zero, this means that some vechiles remain in i junction. This case causes traffic problem ■

Theorem 2

If the maximum vehicle traffic arriving at any junction point i is less than the exit traffic volume at the j neighboring junction points connected to the junction point i, it can be said that there is no possibility of a bottleneck on the roads belonging to the junction point j (Eq.10).

$$\sum_{V_i} c(V_i^{in}) - \sum_{V_j \in N(V_i)} \sum_{k=1}^{|N(V_j,k)^{max}|} c(V_j^{out}) \ < 0 \tag{10}$$

Proof: The volume of traffic arriving i junction is $\sum_{V_i} c(V_i^{in})$ and the volume of traffic leaving j junction which is the neighbour of i junction, is $\sum_{V_j \in N(V_i)} \sum_{k=1}^{|N(V_j,k)^{max}|} c(V_j^{out})$. If the difference between volume of arriving traffic and volume of leaving traffic is less than zero, this means that there is no vechiles in j junction. This case has more traffic volume ■

Theorem 3

If the maximum vehicle traffic arriving at any junction point i is equal to the exit traffic volume at the j neighboring junction points connected to the junction point i, it can be said that there is no possibility of a bottleneck on the roads belonging to the junction point j (Eq.11).

$$\sum_{V_i} c(V_i^{in}) - \sum_{V_j \in N(V_i)} \sum_{k=1}^{|N(V_j,k)^{max}|} c(V_j^{out}) \ = \ 0 \tag{11}$$

Proof: The volume of traffic arriving i junction is $\sum_{V_i} c(V_i^{in})$ and the volume of traffic leaving j junction which is the neighbour of i junction, is $\sum_{V_j \in N(V_i)} \sum_{k=1}^{|N(V_j,k)^{max}|} c(V_j^{out})$. If the difference between volume of arriving traffic and volume of leaving traffic is equal to zero, this means that there is no vechiles in j junction. This case has no traffic problem ■

Theorem 4

The previous theories focused on bottleneck scenarios for a certain vertex point. The maximum flow value of the entire transportation network is given in Equation 12. It is the case when the vehicle traffic arriving at all i junction points is equal to the sum of the k exits of all j junction points connected to the forwards. In this case, it can be said that the traffic flows with the maximum flow for the whole transportation network and is at the saturation limit.

$$\sum_{V_{ij}}^{V_{all}} \left(\sum_{V_i} c(V_i^{in}) - \sum_{V_j \in N(V_i)} \sum_{k=1}^{|N(V_j,k)^{max}|} c(V_j^{out}) \right) \ = 0 \tag{12}$$

Proof: The proofs of Theorem 1, Theorem 2, and Theorem 3 illustrate the traffic volumes at a specific junction. This theorem states the ideal case for no traffic problems on highway (roads). The incoming traffic volumes for all junctions chould be equal to the outgoing traffic volumes for all junctions. This is the best case (ideal case) for highways (roads) traffic arrangement efforts. The main aims of all traffic arrangement/planning is to get ideal case of traffic volume ■

5. Experimental Results

The analysis processes in the study were carried out under three headings. First, the maximum flow value on the specified route in the transportation network, which is weighted with the real vehicle count data, is calculated. Afterward, the bottleneck points that cause the maximum flow value are determined. In this way, considering the improvement for maximum capacity on the determined route, it is aimed to determine the routes to be intervened first in the transportation network. In the second analysis, the most effective junction points of the city were determined according to the maximum capacity values by using the PageRank centrality algorithm, which is very popular in graph theory. These efficiency values give information about the ability of the junction points to meet the traffic load coming to them. Finally, in the last analysis study, a unique method named Average Maximum flow Closeness Algorithm has been proposed. This method produces results on the capacity of the traffic generating points to spread this traffic to the whole city. In this way, it creates a centrality value on the capacity to distribute the traffic density they produce for the entire city. These results generate efficiency values according to the traffic data from the junction points or the traffic-generating source points themselves.

5.1. Detection of maximum flow and bottlenecks of roads

In this section, the maximum flow value between a determined route was calculated, and bottleneck points on this route were determined. In Figure 7, two junction points located in the west-east direction of the city are determined. These points are marked in red. 'Bostanbaşı' junction was chosen as the source point, and 'Emeksiz' junction point was chosen as the sink point. Road connections highlighted in yellow in the figure represent road connections between Bostanbaşı and Emeksiz, where all vehicle flow can take place. The yellow circular nodes represent the junction points where the roads connect, and the gray diamond shape represents the locations that generate one-way vehicle traffic. The enlarged version of the area indicated by the rectangle on the figure on the left in Figure 7 is given in the right part.
Ford-Fulkerson algorithm was applied for the Bostanbaşı-Emeksiz route, and the maximum flow value was determined as 3555 (number of vehicles).

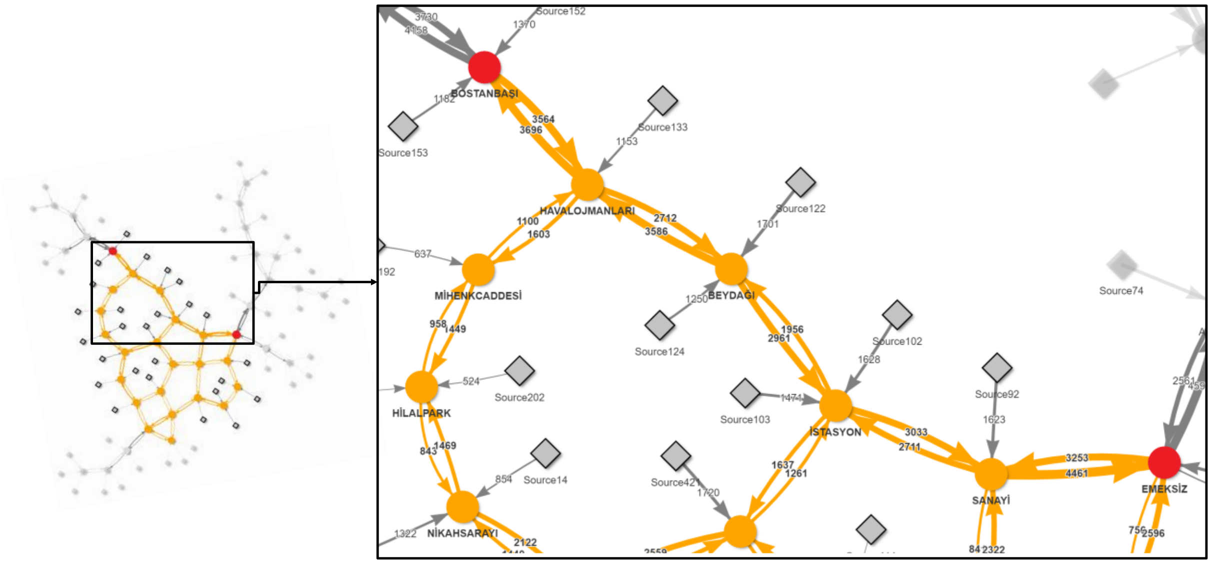

Figure 7. Flows between Source and Sink nodes

Figure 8 shows the edges where the bottleneck occurs on the determined route. The maximum flow value is the sum of the bottleneck edges. When Figure 8 is examined, the Havalojmanları-Beydağı road constitutes the bottleneck points with a maximum of 2712 and Hilalpark-Nikahsarayı road with a maximum of 843 vehicles in 1 hour.
The location of bottleneck points plays a crucial role in increasing traffic capacity. Considering the Bostanbaşı-Emeksiz route, if it is desired to increase the maximum flow here, the first place to focus should be the roads connecting the junction points of Havalojmanları-Beydağı and Hilalpark-Nikahsarayı. By increasing the capacities of these roads, the maximum flow value of the route will also increase.

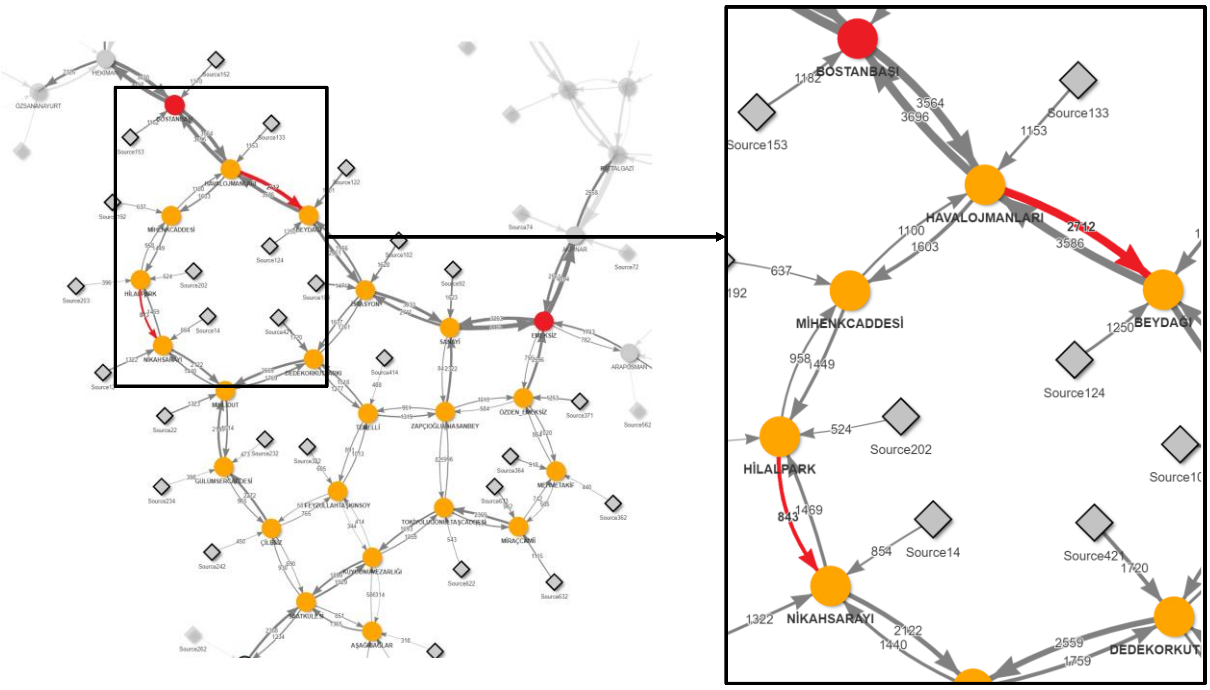

Figure 8. Bottleneck points between Source and Sink nodes

5.2. Junctions efficient value via pagerank algorithm

The PageRank algorithm is applied on the graph to determine the junction points with the maximum demand in the transportation network. In Table 2, the pagerank centrality values of the ten junction points with the highest density and the least density in the transportation network are given. When the values are examined, the Point of Emeksiz junction can be expressed as the junction point that best transfers the traffic flow with the value of 0.05255. The junction point named KonferansSalonu is the junction point with the lowest dominance value with a PageRank centrality value of 0.00858.

In Figure 9, images of the junction points with the highest and lowest PageRank values are given. In the area indicated by the square in the image, the location of the junction points named Emeksiz and Konferans Salonu on the transportation network is provided by zooming in. The edge relations expressed in yellow in the image contain vehicle traffic information coming and going to the relevant junction points. Nodes in green indicate junction points. The sizes of these nodes are visualized in proportion to their PageRank centrality values.

Table 2. Pagerank values of the most effective and most ineffective junction nodes

Ten nodes with the highest centrality value		Ten nodes with the lowest centrality value	
Junction	Pagerank values	Junction	Pagerank values
Emeksiz	0,052559766	Konferanssalonu	0,008583588
Akpınar	0,046014059	Mehmetakif	0,009004943
Battalgazi	0,043730462	Havalimanı	0,009074974
Hekiman	0,041337738	Hanımınçiftliği	0,010827013
Mıhlıdut	0,037891714	Feyzullahtaşkınsoy	0,011039468
Sanayi	0,034062546	Sanayibent	0,011324006
Saatkulesi	0,033643565	Miraçcamii	0,011645474
Bostanbaşı	0,032104338	Aşağıbağlar	0,011781241
Havalojmanları	0,030274251	Altınkayısı	0,011921711
Mişmişpark	0,028772595	Özden_Emeksiz	0,013283945

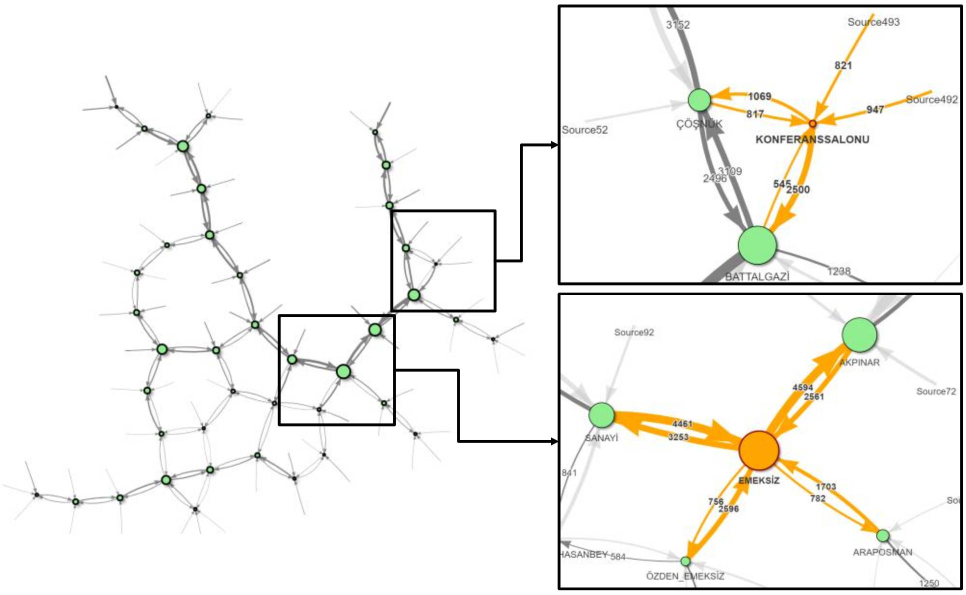

Figure 9. Junction centrality according to PageRank Algorithm

5.3. Determination of efficient nodes via AMFC algorithm (Proposed method's implementation)

By using the maximum flow values, the Average MaxFlow Closeness algorithm calculates how much of this traffic, on average, can be transferred by the locations that generate vehicle traffic to other locations. In Figure 10, the maximum amount of vehicles that the Bostanbaşı junction point can transfer to other junction points in a 1-hour period is given. When the graph is examined, the highest traffic flow with 4158 vehicle flow in 1 hour is between Bostanbaşı and Hekiman junction points. The lowest vehicle flow was realized at the junction named SanayiBent, with 782 vehicles. In other words, a maximum of 782 vehicles can cross in an hour from the Bostanbaşı junction to the junction point called SanayiBentCaddesi. The orange line indicated in Figure 10 is the AMFC (average maximum flow to all junction points) value of the Bostanbaşı junction point.

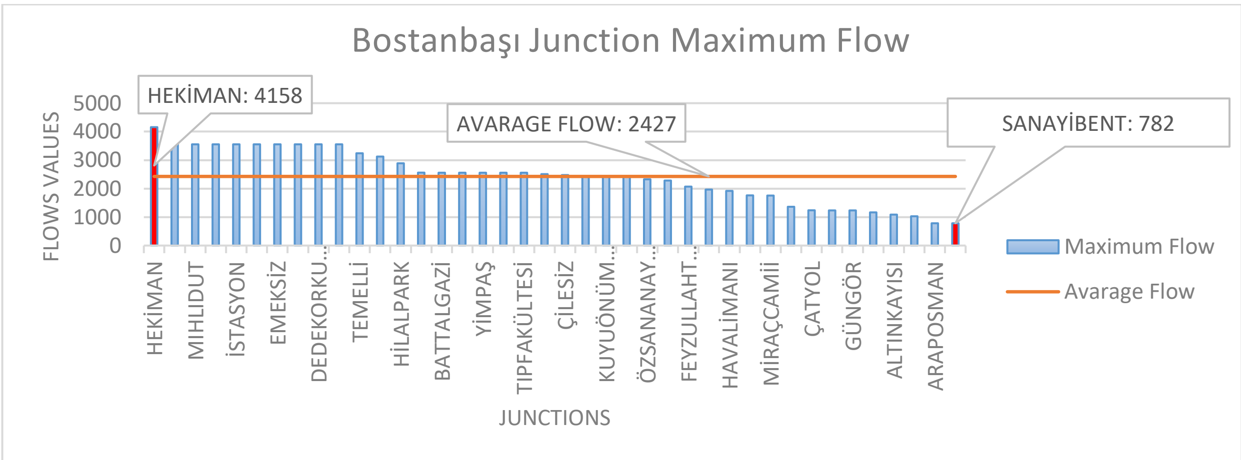

Figure 10. Bostanbaşı junction's AMFC value calculation

As a result of the application of the proposed algorithm to the entire transportation network, the AMFC values of the highest and lowest 10 locations are given in Table 3. When the results are examined, Zapçıoğlu_Hasanbey junction point is the junction point that transfers the traffic density it has to other junction points in the city most efficiently. The AMFC value determined as 2547 for the Zapçıoğlu_Hasanbey junction means that this junction point can transfer 2547 vehicles on average to all junction points of the city without any problems, in line with the maximum flow values calculated by considering the city's 2-year vehicle count data. When the lowest 10 AMFC values are examined, it is seen that these points are not junction points but low-traffic generating nodes. These nodes have been determined as the most ineffective nodes in terms of both the traffic load they produce and their position in the transportation network. The Source541 node is the location that generates the least traffic in the transportation network and transfers the least traffic to other locations at maximum capacity.

Table 3. AMFC values of the most and least effective source nodes

Maximum average flow ten highest nodes		Minimum average flow lowest ten nodes	
Source Node	AMFC values	Source Node	AMFC values
Zapçıoğlu_Hasanbey	2547	Source541	160
İstasyon	2490	Source293	255
Sanayi	2489	Source723	264
Beydağı	2485	Source543	292
Dedekorkutparkı	2477	Source672	318
Özsansanayi	2468	Source42	357
Bostanbaşı	2427	Source262	385
Emeksiz	2423	Source602	385
Havalojmanları	2419	Source273	392
Hekiman	2416	Source203	396

In Figure 11, the most effective and ineffective junction and source points according to the proposed AMFC algorithm are given by zooming in. In the image, the nodes are proportionally sized according to the AMFC value. When the figure is examined, the effectiveness value of both source points and junction points decreases as they move away from the main arteries.

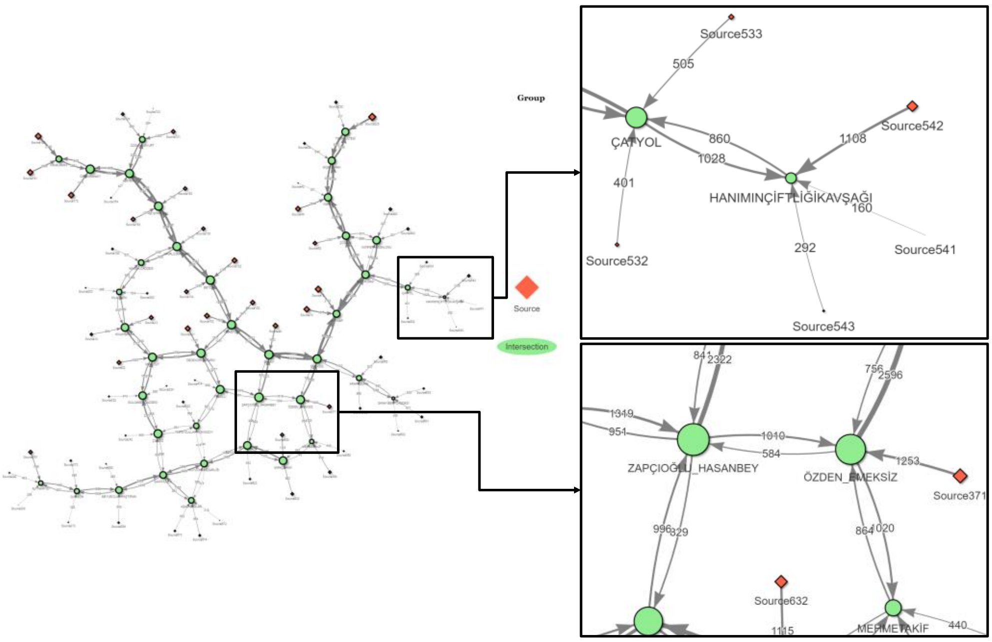

Figure 11. Most and least effective points according to AMFC algorithm

6. Conclusion and Results

In the presented study, a series of analyzes were carried out on the maximum flow approach on the designed transportation network. The designed network is weighted using a city's approximately 24 monthly vehicle count data. The network consisting of 41 junction points and 161 road connections was designed specifically for this study. Vehicle count data on all road connections in the transportation network were filtered in 1-hour intervals, and the maximum vehicle pass value was determined within 1 hour. In light of these data, the entire transportation network has been transformed into a weighted network with the maximum vehicle count data. The vehicle count data at the peak point provides important information about the capacities of the relevant roads. Three different analysis processes were carried out, which will be an important decision support system for managing the transportation system with maximum capacity information. First of all, 2 locations were selected in the east-west regions of the city, and the roads with the maximum vehicle pass value and bottleneck were determined on this route. It is important to identify bottleneck points in regulating vehicle traffic on a route. To increase this route's capacity, the bottleneck roads should be optimized first. Another analysis process, it was carried out on the junction points with the highest vehicle density. According to the maximum traffic load in the transportation network, the most effective junction points were determined by the PageRank algorithm. In this way, the performance of the junction points according to the traffic load they have been determined. The PageRank algorithm and most other centrality algorithms work according to the traffic load that comes to it. When the results of the PageRank algorithm are examined, it is seen that the efficiency value of the junction points on the main streets is high, while the centricity value decreases as you move away from the main street. There is no theory-based graph method for how well the intersection or source (traffic generating locations) points can distribute the maximum traffic load they produce to the entire transportation network. AMFC algorithm, which is an effective method to overcome this deficiency, is proposed in this study. It is presented as a centrality method that determines how much vehicle traffic the traffic-generating node can transfer to the nodes in the entire network at maximum capacity with the AMFC algorithm. When the results are examined, it has been determined that the locations close to the city center and on the main streets have higher flow values. As the distance from the city center increased and the distance from the highway increased, the average maximum flow value decreased. These values obtained as a result of the AMFC algorithm will be an important decision support system in many studies, from routing the traffic in the city to the creation of new road connections. The study has made several unique contributions to the literature. The first significant contribution is the design of a city-specific transportation network based on real-time vehicle counts. Vehicle Count data were obtained from vehicle count cameras in the city's signaling system, and the data were preprocessed. Another unique contribution was presented as the AMFC method by evaluating the maximum flow approach from a different perspective. It is thought that the developed method will provide important conveniences for those who work on transportation systems and graph theory due to its easy-to-apply structure. In the following stages, this analysis will be carried out in a real-time system, and studies will be carried out to optimize the transportation network instantly. Especially with the detection of bottleneck points, estimation processes can be carried out to determine at which intersection point the solution of the problems here can create a bottleneck again.

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Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

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