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Traffic Management at Junctions along Taft Avenue Using Graph Theory

Lea Katrina R. Abanes, Jaimee Antoneth M. Maniago, and Isagani B. Jos*
De La Salle University, 2401 Taft Avenue, 1004 Manila
**Corresponding Author: isagani.jos@dlsu.edu.ph*

Abstract: In order to ease the traffic problem at junctions along Taft Avenue, the use of road manipulation and graph theory concepts have been applied in this paper. After representing the road map in the form of a directed graph, removal of certain traffic flows using genetic algorithm and finding the shortest path using Floyd-Warshall algorithm; the result was a new road layout with reduced traffic congestion.

Key Words: graph theory; Floyd-Warshall algorithm; genetic algorithm; mutation method.

1. INTRODUCTION

Graph theory is a significant part of mathematics with its numerous applications in fields such as technology, geography, and social sciences. It uses graphical modeling in which a structure is converted into a graph with its objects as nodes and connections as edges in order to find a route, optimality or analysis of a given problem. One of its applications is traffic management on road junctions wherein the goal is to search for ways to minimize traffic congestion.

Based on 2015 Numbeo Traffic Index, the Philippines with an average one-way travelling time of 45.50 minutes, dissatisfaction rate of 3,724.39, and index of 202.31 points, placed ninth in the world in terms of negative traffic situation. While on 2015 Global Driver Satisfaction Index, Metro Manila with a score of 0.4 points, rated as ``worst traffic in the world" by the users of traffic and navigation application Waze.

Traffic congestions are caused by the lack of proper infrastructures or alternate routes, and poor public transport options that result in delays, inability to determine travel time, unnecessary fuel consumption, pollution, road rage, and inability of emergency vehicles to respond immediately. Although road construction and highway infrastructures are being built to minimize the flow of traffic, road congestion cannot be prevented due to the large number of vehicles. Therefore it is important to try different methods to handle traffic congestion.

In this study, the main reference used is a journal article entitled ``Application of Graph Theory In Traffic Management" by Saluja, Joshi, and Kashyap from Vellore Institute of Technology [9]. They presented a methodology in handling city traffic by proper traffic management. It involves a 2-point solution: First, to improve the efficiency of roads by reducing traffic accumulation at bottleneck areas. This can be done by reducing the number of interruptions. The result will be a new city map with fewer flow of traffic and interruptions resulting in a more efficient road and reduced congestion problems. Second, to reduce the traffic accumulation at intersections by regulating the flow of traffic. This can be done by controlling the timing patterns of traffic lights based on the capacity of each lane. This in turn led to a smoother driving experience while redistributing traffic as optimally as possible.

One study about traffic management using graph theory is the journal article entitled ``Traffic Control Problems using Graph Connectivity'' by Baruah from Dibrugarh University [1]. The researcher used edge connectivity as well as vertex connectivity as graph theoretic tools to study traffic control problem at an intersection. In order to minimize the waiting time of the traffic participants, the edges which represents the flow of traffic at an intersection can be controlled by placing traffic sensors on each edges or vertex of the transportation network. Their idea was said to have a use in studying traffic control problem at any intersection with more number of traffic streams.

A study by Pasagic, Mikulcic and Marijan [8] examined the selection of optimal traffic signal cycle using graphs. This is a well applied concept of graph theory in traffic management, but only dealt with a traffic signal-controlled intersection. Using graph theory, they were able to analyze two intersections in the city of Zagreb, Dubrovnik Avenue - Veceslava Holjevca Avenue and Savska Road - Street of the City of Vukovar.

This paper is an extension of the journal article "*Application of Graph Theory in Traffic Management*" written by Saluja, Joshi, and Kashyap [9], which in particular, aims to: (1) discuss in detail the definitions, computations and algorithms contained in the paper, (2) apply the latter's first point solution using two edge removal methods (crossover and mutation) to the 2015 Traffic Volume Data of Taft Avenue retrieved from Traffic Engineering Center, and Taft Avenue Distance Data estimated from Department of Public Works and Highways website, *http://dpwh.maps.arcgis.com* and (3) analyze and compare the new road maps obtained from the two methods mentioned in (2).

Moreover, this study is restricted to the algorithms, concepts and definitions found in the main reference. Also, it is limited to apply only the first point solution from the proposed methodology exclusively on the five major junctions along Taft Avenue: Pedro Gil Street (P. Gil), Quirino Avenue, P. Ocampo Street (Vito Cruz), Gil Puyat Avenue (Buendia), and Epifanio de los Santos Avenue (EDSA). Also, unrelated parameters in the study such as road constructions, vehicular accidents and road law violators will not be considered and the efficiency of the modified road maps will still depend on the citizens abiding the law.

Furthermore, this study may be a significant solution in imposing proper traffic management in a junction where traffic congestion usually occurs. Correspondingly, this will be beneficial to the economy and tourism, since transportation of goods and services will be faster; to our health and environment, since minimization of traffic results to minimization of air pollution; and to traffic officers, car owners and commuters since travelling will be hassle-free. More importantly, the study will analyze the traffic management at junctions along Taft Avenue using its road map. Hence, the output of this research will determine the feasibility of the proposed methodology through the fitness function and provide suggestions to further improve the current traffic system by proposing two new optimized road maps.

2. JUNCTIONS ALONG TAFT AVENUE

In this section, a thorough discussion of the road manipulation procedures is given and its application to the road map of Taft Avenue. In order to transform the road map along Taft Avenue consisting of five major junctions namely Pedro Gil-Taft Intersection, Quirino Avenue-Taft Intersection, Vito Cruz-Taft Intersection , Buendia-Taft

Intersection, and EDSA-Taft Intersection from Google Maps (See Appendix A), the following parameters are needed:

- vertices represent the point of intersections of roads across the major junctions
- edges represent the flow of traffic
- weight represent the distance of the flow
- volume of the expected traffic at each flow from 6 a.m - 8 p.m.
-

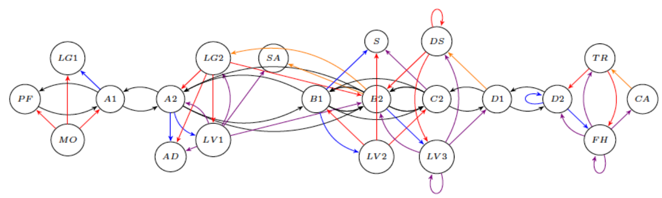
The 21 vertices for the directed graph ***D*** were determined using the points of intersections along Taft Avenue as listed in Table 2.1 below.

Table 2.1. Intersections along Taft Avenue

VERTICES AND STREET NAMES IN THE MAP		
#	Vertex	Location
1	PF	Padre Faura corner Taft Avenue
2	LG1	Leon Guinto Street corner Pedro Gil
3	MO	Maria Orosa Street corner Pedro Gil
4	A1	General Malvar Street corner Taft Avenue
5	A2	Remedios Street corner Taft Avenue
6	LG2	Leon Guinto Street corner Quirino Avenue
7	AD	Adriatico Street corner San Andres
8	LV1	Leveriza Street corner Quirino Avenue
9	SA	San Antonio Street corner San Andres
10	B1	Estrada Street corner Taft Avenue
11	B2	Pablo Ocampo Avenue corner Taft Avenue
12	S	Singalong Street Corner Pablo Ocampo Avenue
13	LV2	Leveriza Street corner Pablo Ocampo Avenue
14	C2	Senator Gil Puyat Avenue corner Taft Avenue
15	DS	Dominga Street corner Gil Puyat Avenue
16	LV3	Leveriza Street corner Gil Puyat Avenue
17	D1	Libertad Avenue corner Taft Avenue
18	D2	Protacio Street corner Taft Avenue
19	TR	Tramo Street corner EDSA
20	FH	F.B. Harrison Street corner EDSA
21	CA	Cuneta Avenue corner Taft Avenue

The edges (traffic lows) and their corresponding weights (distances) were obtained from the Map Data of Department of Public Works and Highways. On the other hand, the volume of the edges were obtained from the Taft Avenue Traffic Volume Data of the Metro Manila Development Authority. The directed graph ***D*** representing the original traffic flow is given in Figure 2.1.

Figure 2.1: The original graph



3. ALGORITHMS

The following algorithms were used to solve for the deviation and check for the connectedness of the digraph (Algorithm 2.1) and to remove certain edges (Algorithm 2.2).

Algorithm 2.1 - Floyd-Warshall Algorithm: This algorithm finds the shortest path between all pairs of vertices *(u-v)*. The algorithm is as follows:

1. First, initialize the distance matrix of a digraph ***D.*** This is done by using the distance matrix **W** of ***D*** and replacing by infinity the entry w_{x-y} where the edge $e = X - Y$, $X = Y$ is not in ***D***.
2. Second, update each values of the initialized distance matrix by finding the shortest path for each edge (*u-v*). Let *d(w-u-v)* be the the length of the shortest path from *u* and *v* that uses only the vertices $v_1, v_2, \ldots, v_k$. There are two possible cases:

- if *w* is not an intermediate vertex in the shortest path from *u* to *v*. We have $w = 0$. Thus, *d(0-u-v)* is the length of the edge from vertex *u* to vertex *w*.
- if *w* is an intermediate vertex in shortest path from *u* to *v*. Then we choose *d(w-u-v)=min{d((w-1)-u-w)+d((w-1)-w-v),d((w-1)-u-v)}*.

Algorithm 2.2 - Genetic Algorithm: This algorithm is an optimization technique used to solve non linear or non differentiable optimization problems. It uses concepts from evolutionary biology to search for a global minimum to an optimization problem. It works by repeatedly modifying a population of individual solutions. The algorithm uses three main types of rules at each step to create the next generation from the current population:

1. *Crossover* rules combine two parents to form children for the next generation.
2. *Mutation* rules apply random changes to individual parents to form children.
3. *Selection* rules select the individuals, called parents, that contribute to the population at the next generation.

4. EDGE REMOVAL

When more than one incoming edge (incoming flow) is at a junction, regardless of the number of outgoing edges (outgoing flow), at least the traffic at one incoming edge has to stop for the others to pass. This is called an *interruption*. Thus, we derive the interruptions at a given vertex *i* using the formula

$$X_i = number \quad of \quad incoming \quad edges \quad minus \ 1$$

These interruptions are the major cause of traffic issues. The objective is to minimize these by removal of edges, yet keeping the graph connected. But the removal of edges causes an increase in distances between some pair of vertices; so, this must be minimized also.

The increase in distance between two vertices *i-j* denoted by Y_{i-j} is called *deviation*. This can be computed by subtracting the original shortest distance of two vertices *d(i-j)* for all pairs of vertices from the modified shortest distance *d'(i'-j')* after removal of edges. The shortest distance between all pairs of vertices can be solved by Floyd-Warshall algorithm using the software *Dev-C++* [5] . Also, it can determine graph connectivity by outputting an infinity if the graph becomes disconnected.

Since we cannot simultaneously minimize the number of interruptions at each vertex and the increase in deviation of pairs of vertices, we need to find an optimum solution for this. Thus, we use a fitness function *F(G)* for a particular graph:

$$F(G) = \Sigma X_i^2 + \Sigma Y_i + \Sigma |id(i) - od(i)|$$

where

X_i = number of interruptions on vertex *i*

Y_i = deviation of shortest path on vertex *i*

$id(i)$ = in degree of vertex *i*

$od(i)$ = out degree of vertex *i*

Note that the number of interruptions on vertex i was squared since its reduction is prioritized over reducing deviations and stalling of vehicles. This fitness function was taken from [9]. The fitness function involves number of interruptions, deviation and stalling. Thus, minimizing this function will be the basis in determining the optimal graph.

Crossover Method

To remove the edges, the concept of genetic algorithm can be used. One rule is the *crossover*, wherein the new (modified) graph obtained from the previous graph is used for the next edge removal stage. To execute the edge removal process using the Crossover Method, we do the following steps:

First, we rank the vertices based on the number of interruptions in a descending manner. Then, at each vertex, we disregard the loops and the incident edges included in the main flow along Taft Avenue since these are major flows that keep the main road connected. We set a threshold at each vertex by averaging the corresponding volume of its remaining incident edges. Starting from the vertex with the most number of interruptions, we remove the incident edges below the threshold starting from the edge with the lowest volume. Also, the connectedness of each graph after removal of edges were checked through finding the shortest distance. We then compute the F(G) for each of the cases. We repeat this procedure and stop when we reach a disconnected graph.

Mutation Method

Another rule from genetic algorithm is *mutation* wherein we remove edges randomly. First, we list all the edges in our graph and sort out the edges that can be removed. Note that loops and edges included in the main flow of Taft Avenue are not candidates for edge removal. Then, from the list, we remove only one edge at a time from the original graph until all the edges from this list have been selected. After a removal of an edge, the shortest distance for all pairs of vertices of the modified graph is computed through Floyd-Warshall algorithm (See Appendix E) to check graph connectivity. If the modified graph is connected, we solve for its fitness function *F(G)* (See Appendix F), otherwise, we disregard the modification. We then solve the *F(G)* of the resulting graph. The edge that gives the minimum *F(G)* value is removed. If there is a tie, we select randomly from any tie edges which gives the minimum *F(G).* The chosen edge will be used for the next mutation until the graph gets disconnected.

5. SUMMARY, DISCUSSION AND CONCLUSION

In order to improve the efficiency of roads in terms of traffic management at the five major junctions along Taft Avenue mentioned in Section 1, we performed road manipulation in which we minimize the interruptions that causes traffic problems by removing certain edges (flows) yet keeping the graph (road map) connected.

We used the two rules in Genetic Algorithm in removing edges: By the Crossover Method, we were able to remove the following edges continuously starting from the vertex with the highest interruption and removing its incident edges from the least weighted edge to the highest weighted edge, until we reached the vertex with the least number of interruptions. At each stage of edge removal we checked the connectedness of the modified graph using the Floyd-Warshall algorithm. The edges removed are as listed below:

Table 5.1. Edges removed by crossover method

Vertex Rank	Vertex	Removal Order	Incident Edges
1	B2	1st	Edge B2-SA
		2nd	Edge LV1-B2
		3rd	Edge LG2-B2
		4th	Edge B2-LG2
		5th	Egde LV3-B2
2	A2	6th	Edge A2-AD
3	C2	7th	Edge LV2-C2
4	AD	8th	Edge LV1-AD
5	PF	9th	Edge MO-PF

The combination of the 9 edges removed as listed on Table 5.1 resulted to a minimum fitness function *F(G)* and is clearly lower than the fitness function of the original graph.

Table 5.2. F(G) values for crossover

	∑(Xi)^2	∑Yi	∑|id(v)-od(v)|	F(G)
Original Graph	114	0 KM	26	140
New Graph (Modified)	75	6.14 KM	18	99.14

By the *mutation method*, all edges were tested on whether its removal will result to a disconnected or a still-connected graph using the Floyd-Warshall algorithm. The edges whose removal will result to a disconnected graph were disregarded. Otherwise, the *F(G)* values for the other edges were computed and the minimum *F(G)* was selected. The edges removed from the 19 mutations are listed below:

Table 5.3. Edges removed using mutation

Mutation #	Edge	Mutation #	Edge	Mutation #	Edge	Mutation #	Edge
1	LV1-A2	6	MO-PF	11	LV3-B2	16	B2-LG2
2	LV1-AD	7	LV2-S	12	FH-D2	17	B2-SA
3	FH-TR	8	LV2-C2	13	A2-AD	18	DS-LV3
4	LV1-B2	9	C2-S	14	LG2-B2	19	LV3-DS
5	MO-LG1	10	LG2-LV1	15	TR-FH		

After removing the 19 edges from Table 5.3, the result was a minimum fitness function F(G) which is lower than the fitness function of the original graph:

Table 5.4. F(G) values for mutation

	∑(Xi)^2	∑Yi	∑|id(v)-od(v)|	F(G)
Original Graph	114	0 KM	26	140
New Graph (Modified)	47	14.5 KM	8	55

The resulting graphs after crossover and mutation are given below.

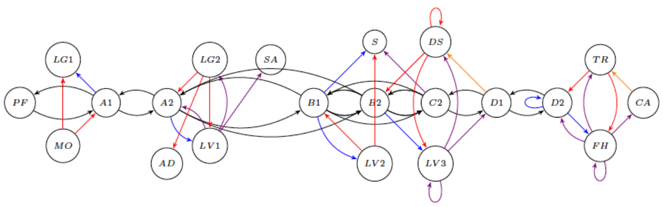


Figure 5.1. Modified graph by crossover method

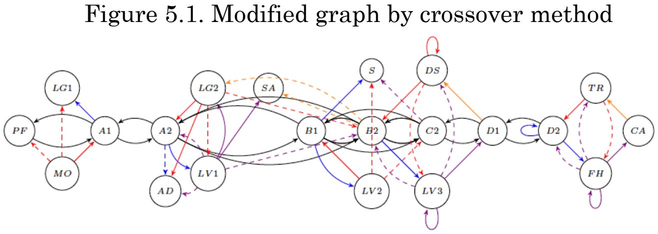


Figure 5.2. Modified graph by mutation method

In this thesis, graph theoretic concepts were applied in formulating the graph of the given road map, a shortest distance algorithm was administered in determining graph connectivity, and two types of rules under genetic algorithm were used for the process of edge removal. In particular, road manipulation was performed in order to minimize interruptions that causes traffic problems at five junctions along Taft Avenue. Two modified road maps were obtained using two methods of edge removal which are better than the original road map. In addition, a fitness function was computed to determine the effectiveness of the modifications. In view of the present subject matter, the following problems may be further considered by the reader: apply road manipulation to the 9 major junctions along Taft Avenue, use a current data (2016) and compare the results, and try other methods of edge removal. Furthermore, this study may be expanded to help in solving the traffic problems not only along some junctions of Taft Avenue but probably to Metro Manila and on nearby suburbs or cities.

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