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作品名稱 Reduction of traffic congestion in España Boulevard using graph theory

得獎獎項 三等獎

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關鍵詞 edge removal、Floyd-Warshall algorithm、genetic algorithm

作者照片

ABSTRACT

There have been numerous studies exploring the applications of graph theory in traffic management, often finding ways to reduce traffic congestion and make traveling more efficient. Such studies will be beneficial when applied to heavily congested areas such as España Boulevard, one of the busiest thoroughfares in Manila. This paper aimed to optimize the road map of España Boulevard using graph theory. The current road map of España Boulevard was represented as a directed graph and subjected to the mutation method of edge removal, wherein an edge is removed in each mutation based on a computed fitness function, *F(G)*, which depicts better efficiency at lower values. Edges were removed until the graph got disconnected, which was tested using the Floyd-Warshall algorithm. The 28th mutation resulted in a minimum *F(G)* value of 144.4; this is a 50.18% decrease from the *F(G)* of the original graph, which is 290. After the 28th mutation, the removals resulted in an increase in the *F(G)*. As a result, the final mutation resulted in an *F(G)* of 311.89, which characterized a less efficient graph. This study was able to apply graph theory concepts to optimize the España Boulevard road map using the mutation method, minimizing its *F(G)* by at most 50.18%. For future studies, the practicality of the alternate road map may be tested in simulations to examine its efficiency when other factors, such as traffic volume, are introduced.

INTRODUCTION

Background of the Study

Urban transportation systems face challenges as communities build more infrastructures globally. Nowadays, people in urban areas have a need to travel faster and more efficiently while heading to their destinations, which in turn intensifies the demand for transportation (Gonçalves & Ribeiro, 2020). As a result of this expansion, private vehicles have taken over urban mobility patterns, resulting in increased congestion in road traffic, accidents that can happen in traffic, and noise and smoke pollution that is produced in traffic. Due to a lack of infrastructure and alternative routes, along with inadequate choices for public transportation, delaying of other people, and mismanagement of time, traffic congestion still thrives. In light of this, road junctions or intersections are used to let vehicular traffic flow in a methodical manner in multiple directions (Designer, 2011). In these intersections, traffic spends less time moving to allow alternation of conflicting traffic flows, consequently becoming congested and thus often becoming traffic bottlenecks in road networks (United Nations Economic Commission for Latin America and the Caribbean, 2003).

Graph theory can be utilized to find optimal paths for different kinds of transportation networks to reduce time consumption for traveling as well as to minimize shipping costs between different locations by using algorithms, such as the Dijkstra's algorithm and Kruskal's algorithm (Vedavathi & Gurram, 2013). Graph theory concepts can also be used as a tool for analyzing flows in transportation systems, which can be applied to evaluate the capacity of existing roadways as well as to design new and effective ones (Guze, 2014). To optimize roadways, a solution for traffic congestion was studied by Setiawan and Budayasa, wherein they made use of graph theory to optimize traffic light phasing at a crossroad, therefore maximizing total time flows and minimizing total waiting time (Setiawan & Budayasa, 2017).

The study of Abanes et al. titled "Traffic Management at Junctions along Taft Avenue Using Graph Theory" made use of graph theory algorithms and road manipulation (Abanes et al., 2017). Abanes et al. transformed the road map of Taft Avenue, a main thoroughfare situated in Metro Manila, into a graph and used it as the basis to come up with new road maps achieved via edge removal. Their study mainly utilized two algorithms; namely, the Floyd-Warshall algorithm and the genetic algorithm.

The Floyd-Warshall algorithm, or the all-pair shortest path algorithm, is the algorithm used to find the shortest path between every pair of vertices in a graph (GeeksforGeeks, 2021a). All of the vertices in the matrix will be treated as intermediate vertices, and each one will be chosen at random to update all shortest paths that involve the chosen vertex as an intermediate vertex. There are two alternative scenarios for each pair of source and destination vertices (i, j). In the shortest path from i to j, the intermediate vertex is not k, the value of dist[i][j] does not change. In the shortest path from i to j, the intermediate vertex is k and dist[i][j] > dist[i][k] + dist[k][j], the value of dist[i][j] will be updated to dist[i][k] + dist[k][j]. The result of the Floyd-Warshall Algorithm is a matrix that represents the least distance from any vertex to all other vertices of the given graph.

The genetic algorithm takes concepts from evolutionary biology and is usually used as a tool to find solutions for search and optimization problems such as the traveling salesman problem (GeeksforGeeks, 2021b). This algorithm simulates the natural selection process among consecutive generations of individuals for solving problems. Fitness scores are assigned to individuals in a generation, where the fitness scores represent each individual's ability to compete in the selection process. Individuals with compatible or optimal fitness scores are chosen for the next generations. Each new generation is thus, on average, more optimal than the previous generation because each new generation provides better options than previous generations.

Abanes et al. utilized a fitness function, *F(G)*, equation referenced from a paper by Saluja et al. (2013), which includes variables that contribute to congestion, namely interruptions, deviations, and stalling. In this case, a graph with a lower fitness function is considered more efficient. By utilizing the two algorithms and the referenced fitness function equation from Saluja et al., the study of Abanes et al. were able to present two alternative road maps that were theoretically more efficient than the current road map of Taft Avenue.

This is particularly relevant because most roads in the urban areas of the Philippines do not have efficient road management of pedestrians and vehicles, especially with motor vehicles, giving rise to issues such as congestion, which is especially seen in Metro Manila (Obinguar & Iryo-Asano, 2021). One of Metro Manila's busiest thoroughfares is España Boulevard (Gabayno, 2014). It is the primary thoroughfare in Manila's Sampaloc District and a part of one of Metro Manila's radial highways. As a result, numerous private cars and public transportation vehicles such as buses and jeepneys pass through España Boulevard and cause traffic congestion during work hours. However, since it is a primary thoroughfare used by many, it is important to have minimal congestions to prevent any further delays in the people’s schedule. Although its road junctions are aided with traffic lights to regulate traffic at road intersections in a methodical manner, it is still heavily congested during work hours due to España Boulevard passing through the northern part of the University Belt, an area that contains multiple schools and universities.

Objectives of the Study

This project aimed to apply graph theory concepts to reduce traffic congestion in España Boulevard by representing its road map as a graph and increasing its efficiency.

Specifically, this study aimed to modify the existing road map of España Boulevard through edge removal to minimize its defined fitness function, which characterizes the efficiency of a road map. It also aimed to identify the effect of the mutation method of edge removal on the efficiency of the road map of España Boulevard by comparing the fitness functions of the original road map and the modified road maps

Significance of the Study

The findings of this study will help traffic enforcement agencies come up with solutions to develop and improve traffic management in Manila by giving a mathematical insight on the efficiency of the current road map of España Boulevard.

In addition, the proposed modifications to the road map of España Boulevard may lessen the inconvenience of commuting along España Boulevard if it is implemented due to the increased theoretical efficiency of the proposed road map. Furthermore, these modifications may also result in lower traffic-induced pollution due to reduced traffic congestion in the area if implemented.

Scope and Limitations

In this study, only the main road roads and intersections (i.e., traffic light intersections) along España Boulevard were part of the graphical representation of the current road map. Moreover, the modifications done to the graph were the results of the mutation method of edge removal; thus, other types of modifications, like edge insertion, are outside the scope of this study. The efficiency of the road maps was solely determined by the values of their fitness functions, which will be computed by using the formula proposed by Saluja et al. (2013).

Consequently, the fitness function formula used in this study only considers interruptions, stalling, and deviation. This means that other traffic-related factors, such as road construction, vehicular accidents, and traffic law violators, were ignored in this study. In addition, the mutation method does not consider traffic volume in the process of edge removal. Although the proposed modification may be theoretically more efficient, the previously mentioned limitations may affect the practicality of the results.

METHODOLOGY

Creation of Original Graph

To represent España Boulevard as a graph, the main intersections along the boulevard as well as the flows of traffic and distances between these intersections were collected from the Department of Public Works and Highways (DPWH) Map Data.

In the original graph, each intersection was represented by a vertex, each flow of traffic was represented by an edge, and the distance of each flow of traffic was represented by the weight of its representative edge. Each vertex and each edge was also labeled with a shortened name for ease of encoding (e.g., "Kundiman Street corner of España Boulevard" may be labeled as vertex "KD"). All of the aforementioned information was encoded into a matrix in Python code via the PyCharm IDE.

Afterwards, the fitness function, F(G), of the original graph was computed. The F(G) formula, Equation [1], was referenced from the paper "Application of Graph Theory in Traffic Management" by Saluja et al. (2013).

$$F(G) = \Sigma X_i^2 + \Sigma Y_i + \Sigma|id(i) - od(i)| \qquad \text{[Equation 1]}$$

X_i or the number of interruptions on vertex i is computed by subtracting one from the number of incoming edges on vertex i. Note that X_i is squared in Equation 1 since its reduction is prioritized over the reduction of deviations and stalling. Y_i or the deviation of shortest path on vertex i is computed by subtracting the shortest distance between two vertices of the original graph i and j from the shortest distance of the modified graph vertices i' and j' for all pairs of vertices in the graph. The shortest distance between all pairs of vertices in the graph can be computed using the Floyd-Warshall algorithm (GeeksforGeeks, 2021). For this study, a Python implementation of the algorithm was used. Lastly, the indegree, *id*(*i*), and outdegree, *od*(i), are simply defined as the incoming and outgoing edges of vertex *i*, respectively. The difference between *id*(*i*) and *od*(*i*), as seen in Equation 1, represents the stalling of vehicles for other vehicles to pass when there are more incoming edges than outgoing edges.

In applying this equation to the original graph, all Y_i was equated to zero since the graph was compared to itself to determine the base fitness function. The computed fitness function from the original graph was then used as the basis to analyze the effectiveness of the resultant graphs throughout the edge removal process.

Removal of Edges via Mutation Method

In the mutation method, the edges in the original graph were listed down and the edges that can be removed without disconnecting the graph were sorted out. In addition, edges included in the main flow of España Boulevard were not considered for removal. Apart from simplicity, the main flow was not considered because it is the main passage between the two ends of the thoroughfare and thus, removing its edges will not translate well into reality given that many vehicles only pass through the main flow. From the list of removable edges, one edge was selected and removed at a time. After each removal, the Floyd-Warshall Algorithm was used to check for the graph connectedness. If the graph was connected, its *F(G)* was computed and listed down; otherwise, the modification was disregarded. The edge whose removal resulted in the minimum *F(G)* was removed from the graph, and the resulting graph was then used for the next generation. When a tie occurs, one was randomly selected for the next generation of removal. This was repeated until the graph got disconnected. After performing the edge removal process, the resultant graph with the smallest fitness function was selected as the optimal road graph.

RESULTS AND DISCUSSION

Creation of Original Graph

Based on the 2021 España Boulevard map of the DPWH Road and Bridge Inventory, the 20 vertices of its graph representation were determined using the points of intersection along España Boulevard as shown in Table 1. The map of España Boulevard may also be seen in Appendix A.

Table 1. Intersections along España Boulevard and their respective vertex codes.

#	Vertex	Location
1	LNR	Lerma Avenue - Nicanor Reyes Street - España Boulevard Intersection
2	PND	Padre Noval Street - Dapitan Street Intersection
3	PNL	Padre Noval Street - S.H. Loyola Street Intersection
4	A	Padre Noval Street - España Boulevard Intersection
5	LAF	Lacson Avenue - Padre Florentino Street Intersection
6	LAL	Lacson Avenue - S.H. Loyola Street Intersection
7	B	Lacson Avenue - España Boulevard Intersection
8	DF	M. Dela Fuente Street - Padre Florentino Street Intersection
9	DL	M. Dela Fuente Street - S.H. Loyola Street Intersection
10	C	M. Dela Fuente Street - España Boulevard Intersection
11	VCF	Vicente Cruz Street - Padre Florentino Street Intersection
12	VCL	Vicente Cruz Street - S.H. Loyola Street Intersection
13	D	Vicente Cruz Street - España Boulevard Intersection
14	MF	Maceda Street - Padre Florentino Street Intersection
15	ML	Maceda Street - S.H. Loyola Street Intersection
16	E	Maceda Street - España Boulevard Intersection
17	BF	Blumentritt Street - Padre Florentino Street Intersection
18	BS	Blumentritt Street - Santo Thomas Street Intersection
19	F	Blumentritt Street - España Boulevard Intersection
20	WR	Welcome Rotonda - España Boulevard Intersection

As seen in Table 1, some vertices were labeled single-letter vertex codes (e.g., A, B, C, etc.); these vertices are the identified major intersections within España Boulevard. Using the identified vertices, a graph for each of these intersections within España Boulevard was constructed (see Appendix B) and combined to form the original graph, as shown in Figure 1 (see next page). The original graph has 84 edges in total, 58 of which are candidates for removal (non-black edges in Figure 1). This graph was also encoded into a matrix, which was used as a template for the edge removal process (see Appendix C). The fitness function of the original graph was computed based on the constructed graph, which resulted in $F(G)=290$.

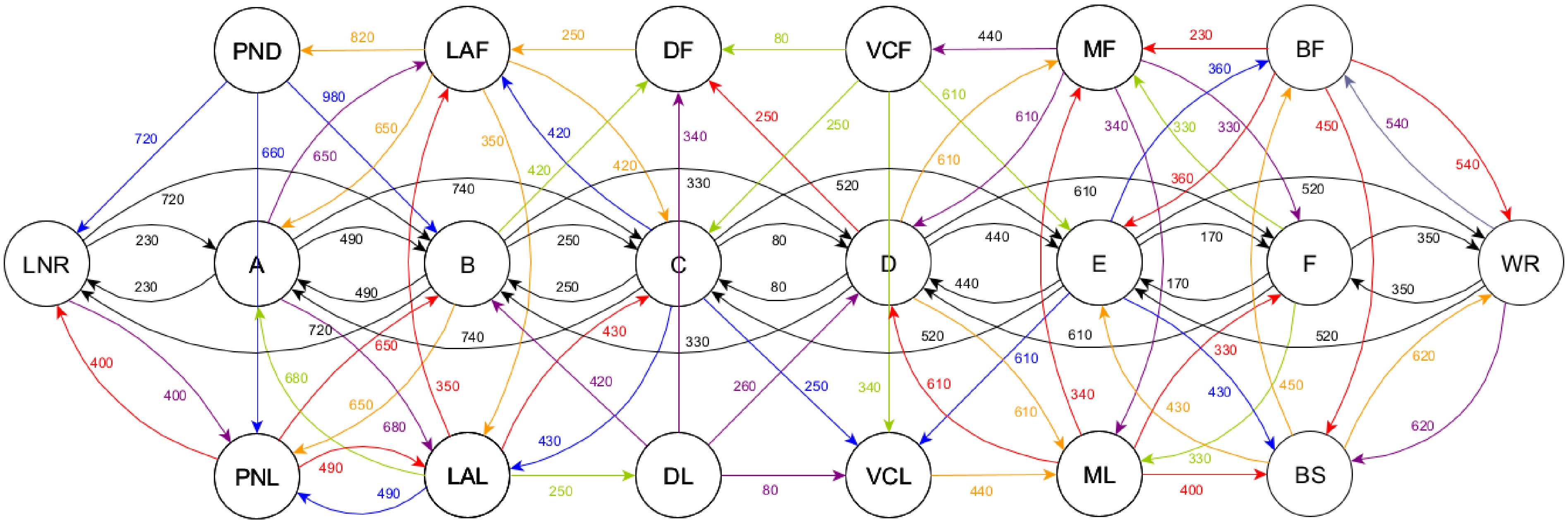

Figure 1. Original graph, the representation of the current road map of España Boulevard. Note that the black-colored edges are part of the main flow and are not candidates for removal, while the non-black edges are candidates for removal.

Results of Edge Removal

In the edge removal process, 43 mutations were performed until the graph got disconnected (see Appendix D). The results of the mutation method show that there was a continuous decrease in the fitness function, *F(G)*, as more mutations were done until the 28th mutation as shown in Figure 2. Subsequent edge removals from the 28th resulted in an increased fitness function. Thus, the positive effect of edge removal on the efficiency of the graph diminishes as more edges are removed from the graph. Furthermore, continuous removal may even result in a graph that is less efficient than the original.

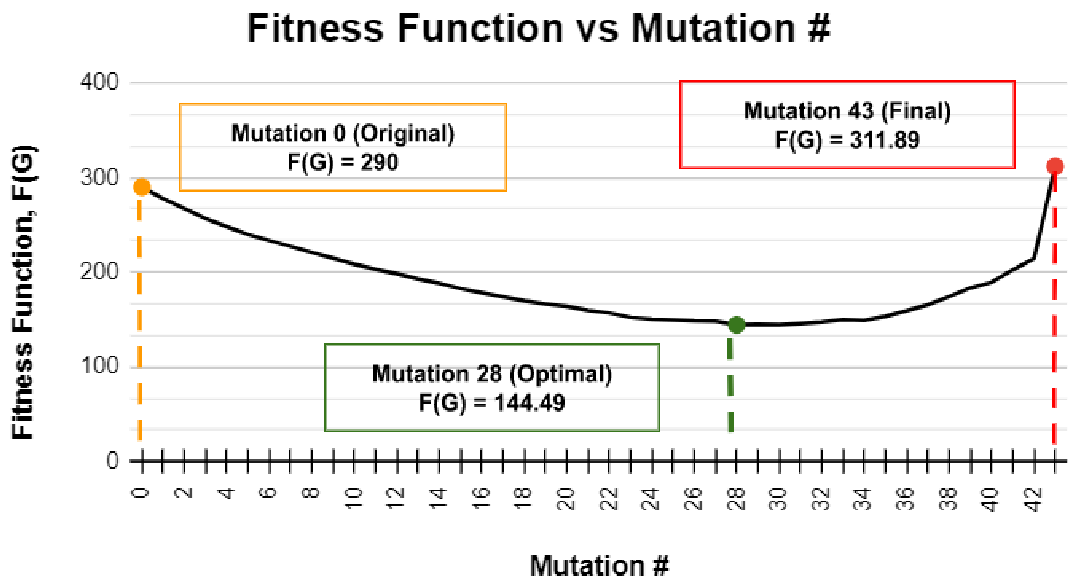

Figure 2. Line graph showing the resulting fitness functions of the mutations, and highlighted in the graph are the F(G)s of mutation 0, 28, and 43.

The resulting graph of the 28th mutation has a computed fitness function of *F(G)=144.49*, which is a 50.18% decrease from the original. This fitness function was the minimum value reached; thus, it was selected as the optimal road map. The low value can be attributed to the significant decrease in interruptions and stalling and a relatively low deviation. The optimal graph has 56 edges in total as shown in Figure 3 (see next page)

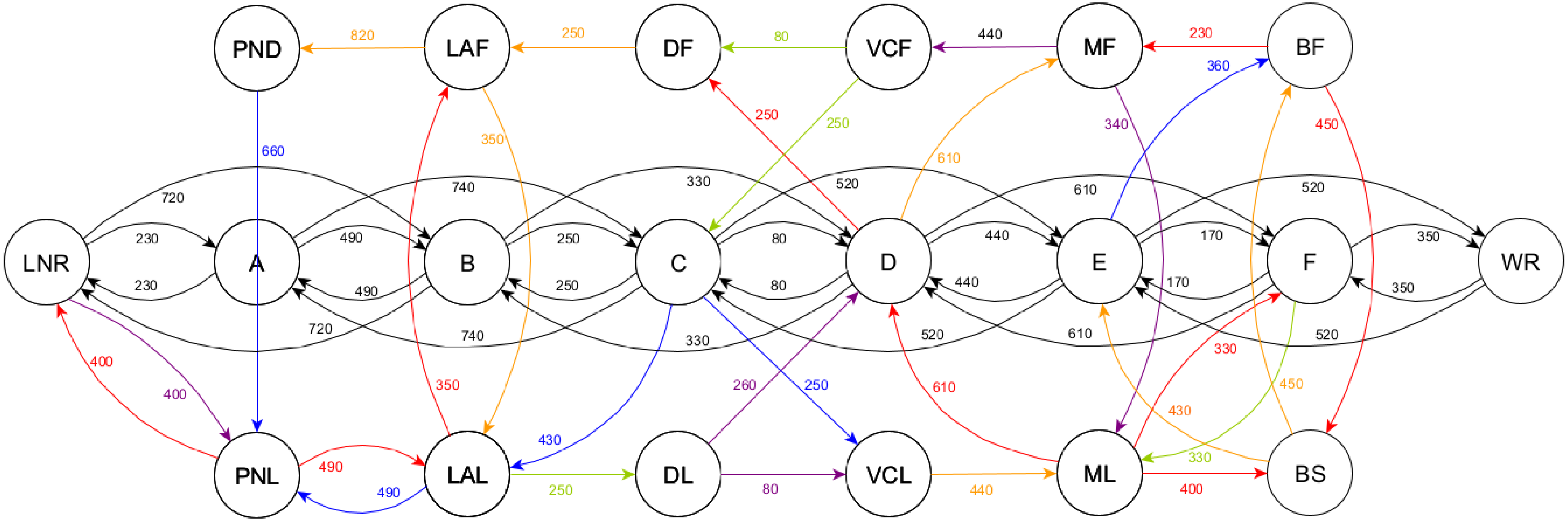

Figure 3. Optimal graph, result of the 28th mutation.

However, the mutations after the 28th resulted in an increased fitness function due to the high increase in deviation as more edges are removed. Ultimately, the resulting graph of the last (43rd) mutation, the final graph, had a computed fitness function of $F(G)=311.89$, which is a 7.55% increase compared to the original. Thus, the final result of the mutation method is theoretically less efficient than the original and is also the maximum fitness function reached. The final graph has 41 edges in total as shown in Figure 4 (see next page).

The summaries for mutation 1 (first), 28 (optimal), and 43 (final) may also be seen in Appendix E. Moreover, the complete list of fitness function computations may be seen at https://bit.ly/MutationData for more data from the edge removal process.

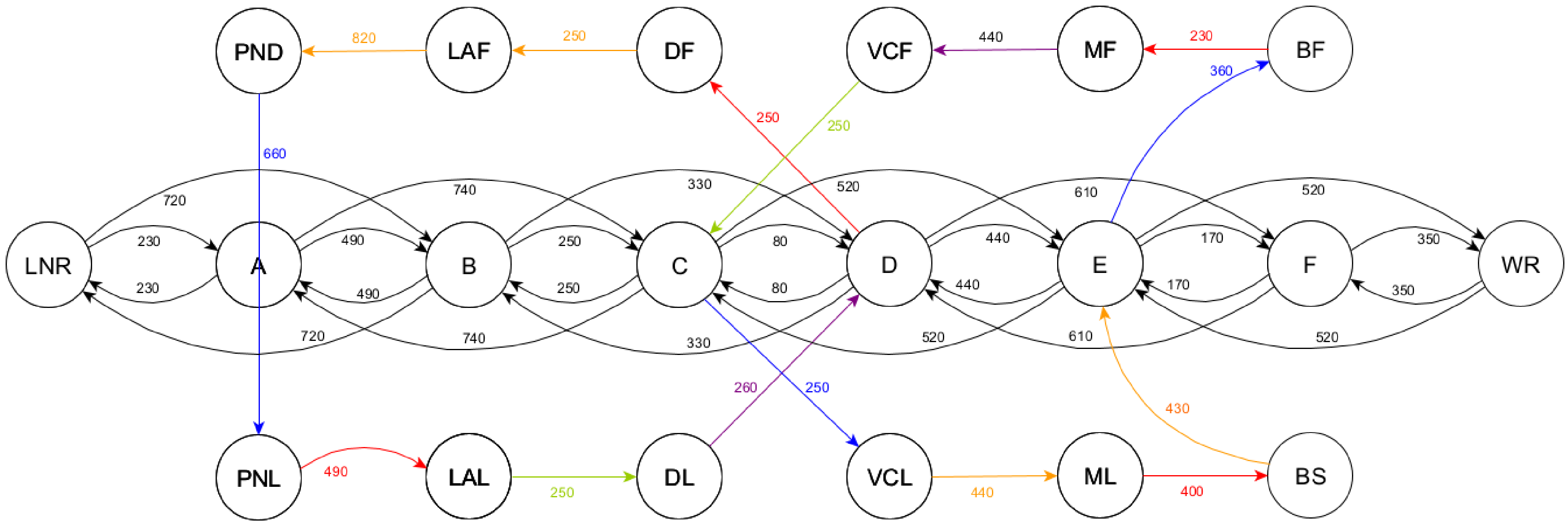

Figure 4. Final graph, result of the 43rd mutation

To compare, the square of the summation of the interruptions at each vertex, or $\Sigma(X_i)^2$, of the modified graphs are notably lower than that of the original graph as shown in Table 2. Since the incoming edge count at a vertex i reduces by one at every removal, the total interruptions will also be reduced at every removal of an edge (see Figure 5).

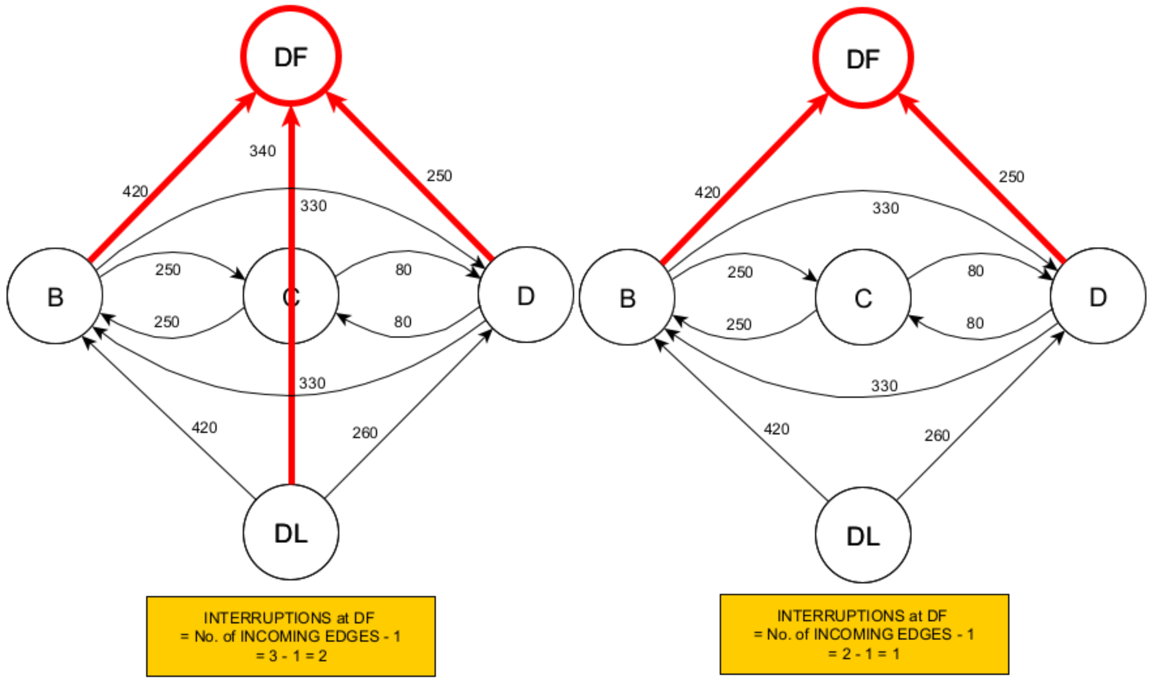

Figure 5. Removing an edge decreases interruptions at a vertex.

Note that the main aim of the edge removal was to minimize the interruptions at each vertex, hence the best case scenario would be to achieve zero interruptions, which characterizes a one-way street. In other words, there would be overall less intersections and thus, less congestion.

Table 2. Comparison of the computed fitness equations of the original and modified graphs.

	Interruptions $\Sigma(X_i)^2$	Deviations ΣY_i	Stalling $\Sigma\lvert id(i)-od(i)\rvert$	Fitness Function F(G)
Original Graph	270	0	20	290
28th Mutation (Optimal)	102	36.49	6	144.49
43rd Mutation (Final)	67	244.89	0	311.89

Contrarily, the summations of the deviation of the shortest path at each vertex, or ΣY_i, of the modified graphs are larger than that of the original graph. This increase is due to the fact that every time an edge from the graph is removed, the shortest path between two vertices may have been altered due to the removal; thus, it deviates from the base value held by the original graph. For example, removing the edge connecting vertex DL to vertex DF from the original graph changes the shortest path and consequently increases the shortest distance between the vertices by 170 meters (see Figure 6).

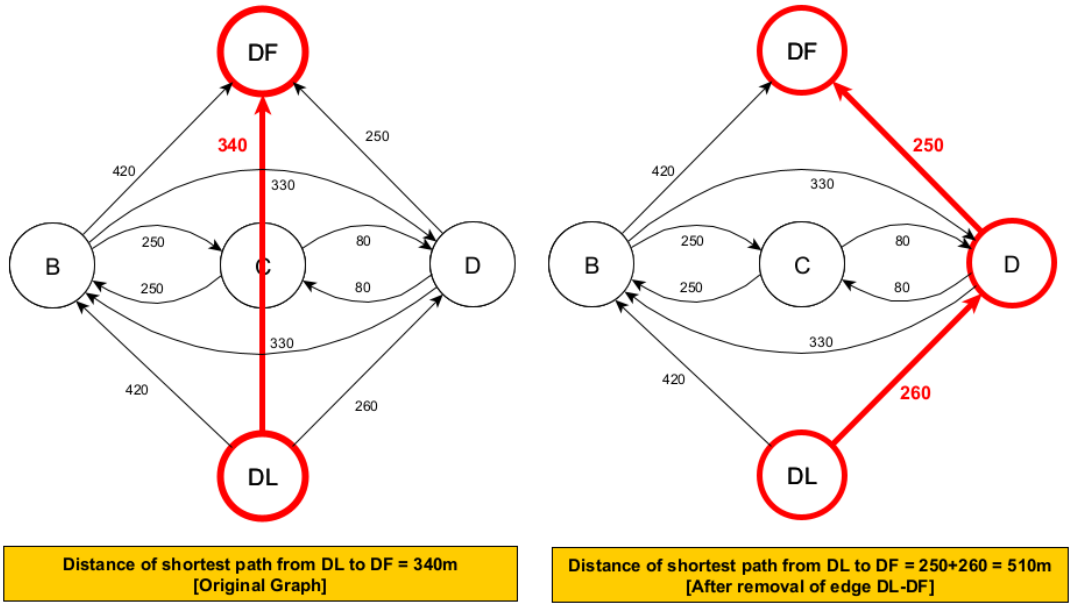

Figure 6. Comparison of shortest path distance between original graph (left) and graph after removal of edge DL-DF (right), illustrating the deviation of shortest paths when removing edges.

Hence, it should be noted that the interruptions were reduced at the overall cost of having to travel farther distances between two points. Moreover, this effect is more prominent in the fitness function of the final graph because removing more edges from the graph may result in the removal of certain edges that are essential in shortening certain paths. For example, the shortest path from vertex LAF to vertex LAL in the optimal graph only goes through one edge (see Figure 7). However, this edge is not present in the final graph and the shortest path from vertex to LAF to vertex LAL in the final graph goes through other edges instead, which increases the shortest distance between the two vertices by 1620 meters (see Figure 8).

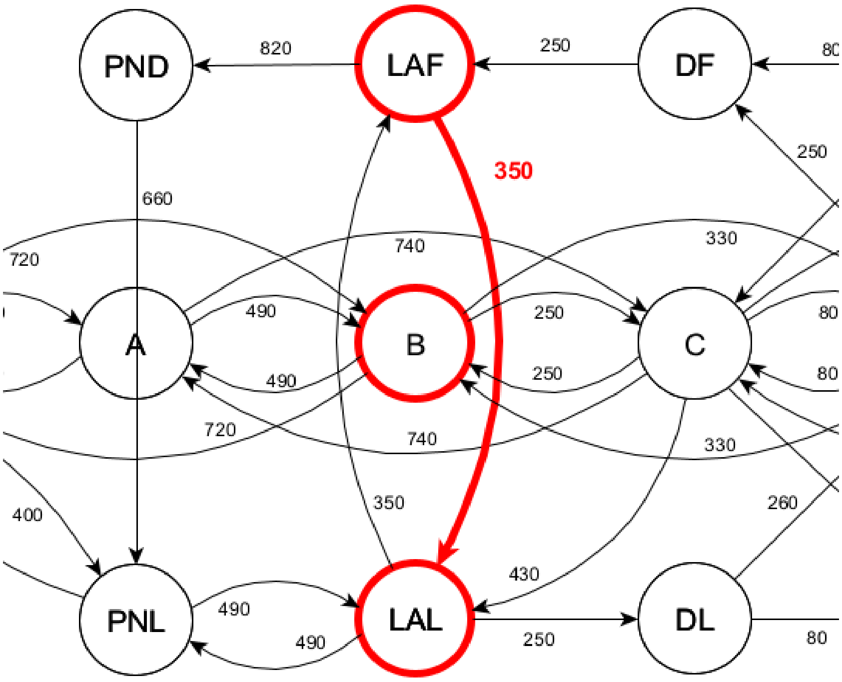

Figure 7. Shortest path from LAF to LAL in the Optimal Graph (distance = 350 m).

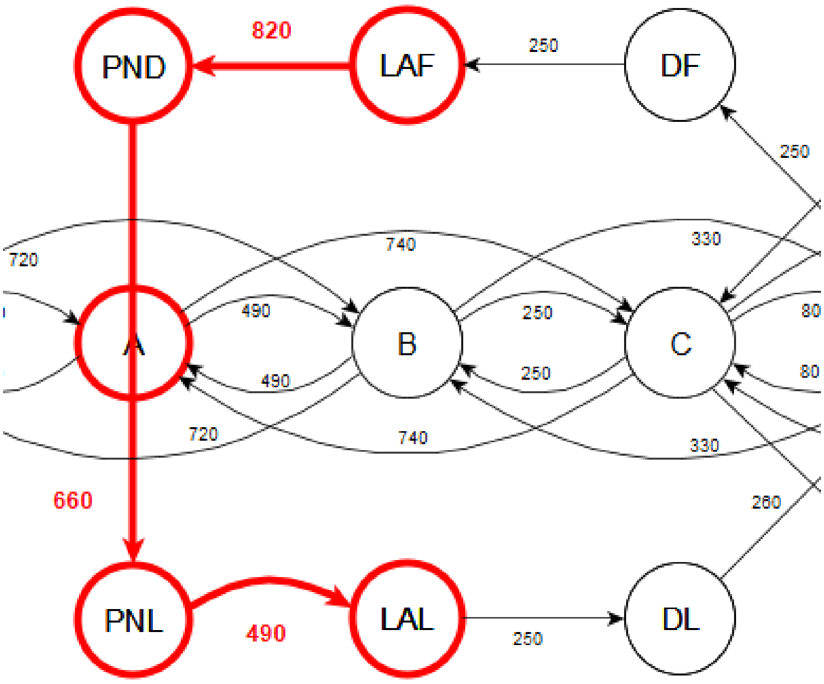

Figure 8. Shortest path from LAF to LAL in the Final Graph (distance = 1970 m).

Lastly, the summation of the difference between the in degree and out degree at each vertex, or $\Sigma|id(i)\text{-}od(i)|$, also significantly reduced compared to that of the original graph. This means that there are more intersections that have equal incoming and outgoing lanes, which also means that there is less stalling in the intersections of the modified graphs. Furthermore, this can be better illustrated by the final graph (see Figure 4), which has 0 stalling. It can be observed that all of its edges that are not part of the main flow (colored edges) are one-way paths.

The project can be translated into real-world scenarios to make it easier to understand. Using the previous example (Figure 7 and Figure 8), the vertices to be focused on are vertices LAF and LAL. In the optimal graph, one arrow pointing from LAF to LAL and vice versa indicates that there is a two way path from these vertices. However, since there are no arrows pointing from LAL to A, you cannot make a left turn in that area. You just go straight to LAF. You also cannot make a right turn since there are no arrows pointing from LAL to C. On the other hand, there are no arrows pointing from LAF to LAL and vice versa in the final graph, indicating that the two-way path has been eliminated. The path from LAF to LAL will be one way as shown with only one arrow pointing to each vertex in Figure 8.

SUMMARY AND CONCLUSION

The existing road map of España Boulevard was represented as a graph to optimize it by edge removal via the mutation method. The original graph had a computed fitness function of *F(G)*=290. Performing the mutation method of edge removal resulted in a decreased fitness function until the 28th mutation, which generated the optimal graph. It had a computed fitness function of *F(G)*=144.49, which is 50.18% lower than the original. The fitness function of the optimal graph was the minimum reached and thus, is theoretically the most efficient resulting graph from the edge removal process. However, completing the entire edge removal process until the graph gets disconnected resulted in a graph that is less efficient because the final graph had a computed fitness function of *F(G)*=311.89, which is 7.55% higher than the original.

Finally, it may be concluded that this study was able to apply basic graph theory concepts to propose an alternative road map to the current road map of España Boulevard, the optimal graph, which had a significantly smaller fitness function than the original. Thus, it is theoretically more efficient. Although one of the resultant graphs from the mutation method was optimal, completing the entire process resulted in a graph that is less efficient. This shows that the removal of edges mainly has a positive effect when there are more edges in the graph but this positive effect diminishes, and may even result in a negative effect, as more edges are removed. Hence, there should be a balance between removing interruptions and maintaining pathways between intersections.

RECOMMENDATIONS

The results of this study are theoretical in nature and, as mentioned in the Scope and Limitations section of this paper, our methodology does not consider many practical factors like traffic volume and accident susceptibility. Thus, the results of this study may be enriched by incorporating these factors using available road network simulations. In addition, future studies can use other ways of modifying road maps, may it be other methods of edge removal (e.g., crossover method) or even entirely different techniques to optimize road maps using graph theory concepts. Lastly, future research may also consider creating a program that can automate the process of optimizing existing road maps.

ACKNOWLEDGEMENT

The researchers of this study would like to thank Mr. Isagani, who lended an electronic copy of the paper he co-authored, “Traffic Management at Junctions Along Taft Avenue Using Graph Theory”, which served as the main reference for this study.

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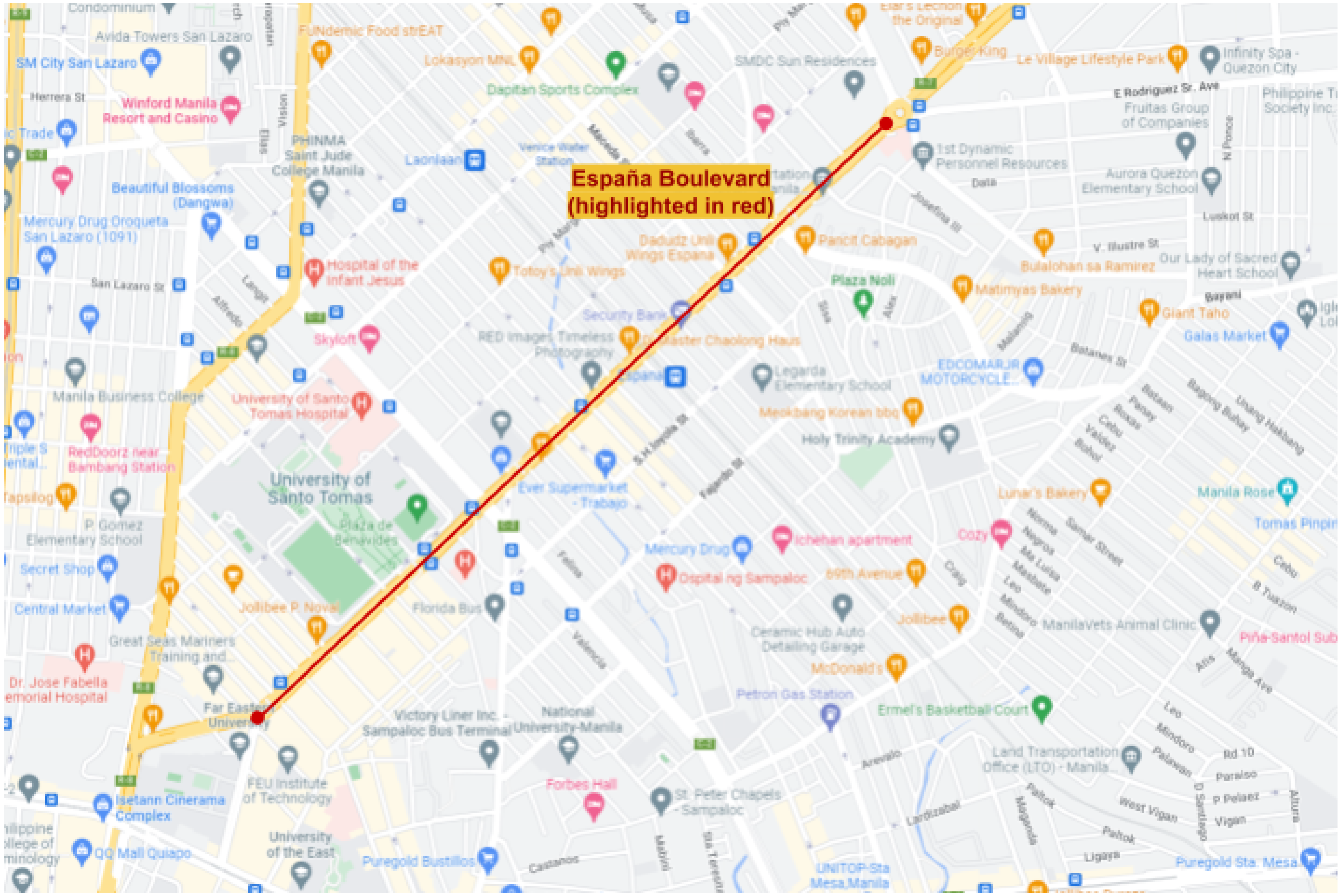
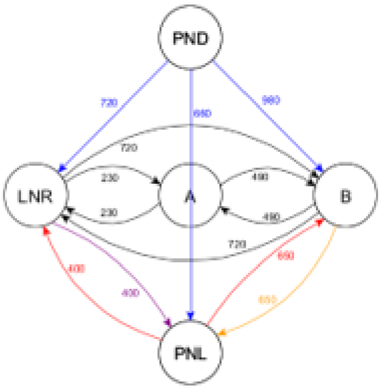
APPENDICES

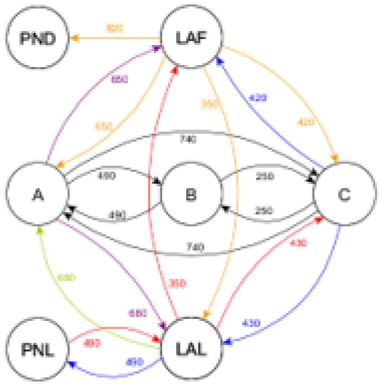
APPENDIX A: GOOGLE MAP SNIPPET OF ESPAÑA BOULEVARD



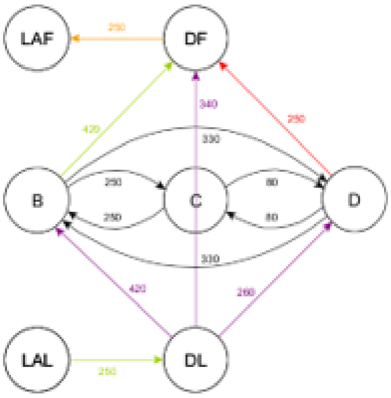
APPENDIX B: STREET INTERSECTION SUBGRAPHS



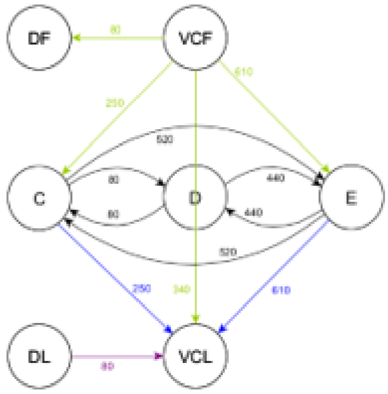
PADRE NOVAL ST.-ESPAÑA BLVD. CORNER



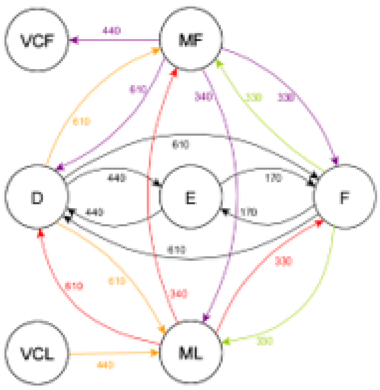
LACSON ST.-ESPAÑA BLVD. CORNER



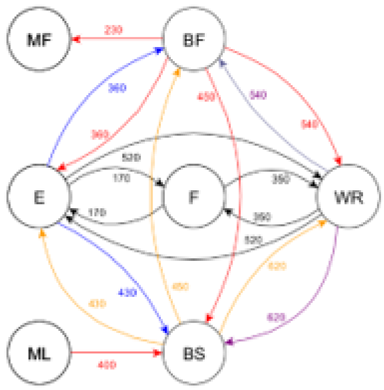
M. DELA FUENTE ST. ESPAÑA BLVD. CORNER



VICENTE CRUZ ST.-ESPAÑA BLVD. CORNER



MACEDA ST.-ESPAÑA BLVD. CORNER



BLUMENTRITT ST.-ESPAÑA BLVD. CORNER

APPENDIX C: CODE TEMPLATE FOR FLOYD-WARSHALL ALGORITHM

```
# Python Program for Floyd Warshall Algorithm

# Number of vertices in the graph
V = 20

# Define infinity as the large
# enough value. This value will be
# used for vertices not connected to each other
INF = 999999

# Solves all pair shortest path
# via Floyd Warshall Algorithm

def floydWarshall(graph):
    # ADDED VARIABLE FOR SUM OF SHORTEST PATHS
    SUM = 0
    dist = list(map(lambda i: list(map(lambda j: j, i)), graph))

    for k in range(V):

        # pick all vertices as source one by one
        for i in range(V):

            # Pick all vertices as destination for the
            # above picked source
            for j in range(V):
                # If vertex k is on the shortest path from
                # i to j, then update the value of dist[i][j]
                dist[i][j] = min(dist[i][j],
                                 dist[i][k] + dist[k][j])

    printSolution(dist)

    # ADDED CODE FOR PRINTING SUM OF SHORTEST PATHS
    for x in range(len(dist)):
        SUM += sum(dist[x])
    print("Sum of Shortest Paths on Each Vertex: ")
    print(SUM)

# A utility function to print the solution
def printSolution(dist):
    print("Following matrix shows the shortest distances\
 between every pair of vertices")

    for i in range(V):
        for j in range(V):
            if (dist[i][j] == INF):
                print("%7s" % ("INF"), end=" ")
            else:
                print("%7d\t" % (dist[i][j]), end=' ')



#Matrix representation of the original graph
graph = [[  0, INF, INF, 230, INF, INF, 720, INF, INF, INF, INF, INF, INF,
INF, INF, INF, INF, INF, INF, INF],
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          [720,   0, 660, INF, INF, INF, 980, INF, INF, INF, INF, INF, INF,
INF, INF, INF, INF, INF, INF, INF],
          [400, INF,   0, INF, INF, 490, 650, INF, INF, INF, INF, INF, INF,
INF, INF, INF, INF, INF, INF, INF],
          [230, INF, INF,   0, 650, 680, 490, INF, INF, 740, INF, INF, INF,
INF, INF, INF, INF, INF, INF, INF],
          [INF, 820, INF, 650,   0, 350, INF, INF, INF, 420, INF, INF, INF,
INF, INF, INF, INF, INF, INF, INF],
          [INF, INF, 490, 680, 350,   0, INF, INF, 250, 430, INF, INF, INF,
INF, INF, INF, INF, INF, INF, INF],
          [720, INF, 650, 490, INF, INF,   0, 420, INF, 250, INF, INF, 330,
INF, INF, INF, INF, INF, INF, INF],
          [INF, INF, INF, INF, 250, INF, INF,   0, INF, INF, INF, INF, INF,
INF, INF, INF, INF, INF, INF, INF],
          [INF, INF, INF, INF, INF, INF, 420, 340,   0, INF, INF,  80, 260,
INF, INF, INF, INF, INF, INF, INF],
          [INF, INF, INF, 740, 420, 430, 250, INF, INF,   0, INF, 250,  80,
INF, INF, 520, INF, INF, INF, INF],
          [INF, INF, INF, INF, INF, INF, INF,  80, INF, 250,   0, 340, INF,
INF, INF, 610, INF, INF, INF, INF],
          [INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF,   0, INF,
INF, 440, INF, INF, INF, INF, INF],
          [INF, INF, INF, INF, INF, INF, 330, 250, INF,  80, INF, INF,   0,
610, 610, 440, INF, INF, 610, INF],
          [INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, 440, INF, 610,
0, 340, INF, INF, INF, 330, INF],
          [INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, 610,
340,   0, INF, INF, 400, 330, INF],
          [INF, INF, INF, INF, INF, INF, INF, INF, INF, 520, INF, 610, 440,
INF, INF,   0, 360, 430, 170, 520],
          [INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF,
230, INF, 360,   0, 450, INF, 540],
          [INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF,
INF, INF, 430, 450,   0, INF, 620],
          [INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, 610,
330, 330, 170, INF, INF,   0, 350],
          [INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF, INF,
INF, INF, 520, 540, 620, 350,   0]]

# Print the solution
floydWarshall(graph)

# This code is adapted from contributed code by Mythri J L from
GeekforGeeks
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APPENDIX D: RESULTING FITNESS FUNCTIONS OF EACH MUTATION

Mutation #	F(G)	Mutation #	F(G)
0	290	22	156.95
1	277.69	23	152.32
2	267.01	24	150.28
3	256.75	25	149.58
4	248.07	26	148.66
5	239.85	27	148.38
6	233.49	28	144.49
7	227.17	29	145.08
8	220.85	30	144.64
9	214.76	31	145.95
10	208.47	32	147.45
11	203.1	33	149.88
12	198.42	34	149.15
13	192.96	35	153.45
14	188.28	36	159.19
15	182.62	37	165.61
16	178.26	38	174.27
17	173.96	39	183.34
18	169.76	40	189.25
19	166.59	41	202.57
20	163.82	42	214.45
21	159.62	43	311.89

APPENDIX E: SUMMARIES OF MUTATIONS 1, 28, AND 43

MUTATION 1

	From	To	Outcome	Verdict	F(G)
PADRE NOVAL					
1	LNR	PNL	connected	removable	286.52
2	PND	LNR	connected	removable	283.68
3	PND	PNL	connected	removable	284.48
4	PND	B	connected	removable	280.44
5	PNL	LNR	connected	removable	286.5
6	PNL	B	connected	removable	279.58
7	B	PNL	connected	removable	285.88
LACSON					
	From	To	Outcome	Verdict	F(G)
8	A	LAF	connected	removable	288.48
9	A	LAL	connected	removable	287.64
10	LAF	PND	disconnected	disregard	-
11	LAF	A	connected	removable	286.52
12	LAF	LAL	connected	removable	289.88
13	LAF	C	connected	removable	287.87
14	LAL	PNL	connected	removable	284.72
15	LAL	A	connected	removable	283.32
16	LAL	LAF	connected	removable	286.96
17	LAL	C	connected	removable	279.16
18	PNL	LAL	connected	removable	291.47
19	C	LAL	connected	removable	293.33
20	C	LAF	connected	removable	287.32
M. DELA FUENTE					
	From	To	Outcome	Verdict	F(G)
21	B	DF	connected	removable	285.65
22	DF	LAF	disconnected	disregard	-
23	DL	B	connected	removed	277.69
24	DL	DF	connected	removable	283.68
25	DL	D	connected	removable	280.62
26	LAL	DL	disconnected	disregard	-
27	D	DF	connected	removable	286.44
VICENTE CRUZ					
	From	To	Outcome	Verdict	F(G)
28	C	VCL	connected	removable	286.74
29	VCF	DF	connected	removable	286.2
30	VCF	C	connected	removable	280.69
31	VCF	VCL	connected	removable	283.48
32	VCF	E	connected	removable	279.78
33	DL	VCL	connected	removable	285.95
34	E	VCL	connected	removable	285.68
MACEDA					
	From	To	Outcome	Verdict	F(G)
35	D	MF	connected	removable	292.47
36	D	ML	connected	removable	287.16
37	MF	VCF	disconnected	disregard	-
38	MF	D	connected	removable	281.16
39	MF	ML	connected	removable	287.8
40	MF	F	connected	removable	286.35
41	ML	D	connected	removable	286.45
42	ML	MF	connected	removable	288.32
43	ML	F	connected	removable	287.1
44	VCL	ML	disconnected	disregard	-
45	F	ML	connected	removable	288.11
46	F	MF	connected	removable	288.1
BLUMENTRITT					
	From	To	Outcome	Verdict	F(G)
47	E	BF	connected	removable	295.84
48	E	BS	connected	removable	286.77
49	BF	MF	connected	removable	287.95
50	BF	E	connected	removable	279.74
51	BF	BS	connected	removable	283.34
52	BF	WR	connected	removable	285.34
53	BS	E	connected	removable	285.5
54	BS	BF	connected	removable	289.86
55	BS	WR	connected	removable	287.33
56	ML	BS	connected	removable	286.88
57	WR	BS	connected	removable	285.33
58	WR	BF	connected	removable	289.34

MUTATION 28 [MINIMUM/OPTIMAL]

	From	To	Outcome	Verdict	F(G)
PADRE NOVAL					
1	LNR	PNL	connected	removable	149.69
2	PND	LNR	removed in mutation 7		
3	PND	PNL	disregarded in mutation 21		
4	PND	B	removed in mutation 20		
5	PNL	LNR	connected	removable	156.12
6	PNL	B	removed in mutation 9		
7	B	PNL	removed in mutation 10		
LACSON					
	From	To	Outcome	Verdict	F(G)
8	A	LAF	removed in mutation 25		
9	A	LAL	remoced in mutation 16		
10	LAF	PND	disregarded in mutation 1		
11	LAF	A	removed in mutation 13		
12	LAF	LAL	connected	removable	197.78
13	LAF	C	removed in mutation 26		
14	LAL	PNL	connected	removable	155.98
15	LAL	A	removed in mutation 17		
16	LAL	LAF	connected	removable	153.3
17	LAL	C	removed in mutation 2		
18	PNL	LAL	connected	removable	170.35
19	C	LAL	connected	removable	155.65
20	C	LAF	removed in mutation 12		
M. DELA FUENTE					
	From	To	Outcome	Verdict	F(G)
21	B	DF	removed in mutation 21		
22	DF	LAF	disregarded in mutation 1		
23	DL	B	removed in mutation 1		
24	DL	DF	removed in mutation 8		
25	DL	D	connected	removable	171.15
26	LAL	DL	disregarded in mutation 1		
27	D	DF	connected	removable	164.4
VICENTE CRUZ					
	From	To	Outcome	Verdict	F(G)
28	C	VCL	connected	removable	153.98
29	VCF	DF	connected	removable	149.88
30	VCF	C	connected	removable	154.99
31	VCF	VCL	removed in mutation 18		
32	VCF	E	removed in mutation 5		
33	DL	VCL	connected	removable	154.8
34	E	VCL	removed in mutation 6		
MACEDA					
	From	To	Outcome	Verdict	F(G)
35	D	MF	connected	removable	159.04
36	D	ML	removed in mutation 14		
37	MF	VCF	disregarded in mutation 1		
38	MF	D	removed in mutation 4		
39	MF	ML	connected	removable	152.74
40	MF	F	removed in mutation 19		
41	ML	D	connected	removable	148.97
42	ML	MF	removed in mutation 15		
43	ML	F	connected	removable	150.93
44	VCL	ML	disregarded in mutation 1		
45	F	ML	connected	removable	149.35
46	F	MF	removed in mutation 24		
BLUMENTRITT					
	From	To	Outcome	Verdict	F(G)
47	E	BF	connected	removable	154.03
48	E	BS	removed in mutation 11		
49	BF	MF	connected	removable	166.11
50	BF	E	removed in mutation 3		
51	BF	BS	connected	removable	150.27
52	BF	WR	removed in mutation 27		
53	BS	E	connected	removable	150.43
54	BS	BF	connected	removable	146.47
55	BS	WR	removed in mutation 22		
56	ML	BS	connected	removable	157.25
57	WR	BS	removed in mutation 23		
58	WR	BF	connected	removed	144.49

MUTATION 43 [FINAL]

	From	To	Outcome	Verdict	F(G)
PADRE NOVAL					
1	LNR	PNL	removed in mutation 31		
2	PND	LNR	removed in mutation 7		
3	PND	PNL	disregarded in mutation 21		
4	PND	B	removed in mutation 20		
5	PNL	LNR	removed in mutation 36		
6	PNL	B	removed in mutation 9		
7	B	PNL	removed in mutation 10		
LACSON					
	From	To	Outcome	Verdict	F(G)
8	A	LAF	removed in mutation 25		
9	A	LAL	remoced in mutation 16		
10	LAF	PND	disregarded in mutation 1		
11	LAF	A	removed in mutation 13		
12	LAF	LAL	connected	removed	311.89
13	LAF	C	removed in mutation 26		
14	LAL	PNL	removed in mutation 42		
15	LAL	A	removed in mutation 17		
16	LAL	LAF	removed in mutation 35		
17	LAL	C	removed in mutation 2		
18	PNL	LAL	disregarded in mutation 37		
19	C	LAL	removed in mutation 41		
20	C	LAF	removed in mutation 12		
M. DELA FUENTE					
	From	To	Outcome	Verdict	F(G)
21	B	DF	removed in mutation 21		
22	DF	LAF	disregarded in mutation 1		
23	DL	B	removed in mutation 1		
24	DL	DF	removed in mutation 8		
25	DL	D	disregarded in mutation 38		
26	LAL	DL	disregarded in mutation 1		
27	D	DF	disregarded in mutation 33		
VICENTE CRUZ					
	From	To	Outcome	Verdict	F(G)
28	C	VCL	disregarded in mutation 38		
29	VCF	DF	removed in mutation 32		
30	VCF	C	disregarded in mutation 33		
31	VCF	VCL	removed in mutation 18		
32	VCF	E	removed in mutation 5		
33	DL	VCL	removed in mutation 37		
34	E	VCL	removed in mutation 6		
MACEDA					
	From	To	Outcome	Verdict	F(G)
35	D	MF	removed in mutation 38		
36	D	ML	removed in mutation 14		
37	MF	VCF	disregarded in mutation 1		
38	MF	D	removed in mutation 4		
39	MF	ML	removed in mutation 39		
40	MF	F	removed in mutation 19		
41	ML	D	removed in mutation 29		
42	ML	MF	removed in mutation 15		
43	ML	F	removed in mutation 40		
44	VCL	ML	disregarded in mutation 1		
45	F	ML	removed in mutation 30		
46	F	MF	removed in mutation 24		
BLUMENTRITT					
	From	To	Outcome	Verdict	F(G)
47	E	BF	disregarded in mutation 34		
48	E	BS	removed in mutation 11		
49	BF	MF	disregarded in mutation 35		
50	BF	E	removed in mutation 3		
51	BF	BS	removed in mutation 34		
52	BF	WR	removed in mutation 27		
53	BS	E	disregarded in mutation 34		
54	BS	BF	removed in mutation 33		
55	BS	WR	removed in mutation 22		
56	ML	BS	disregarded in mutation 35		
57	WR	BS	removed in mutation 23		
58	WR	BF	removed in mutation 28		

【評語】010048

In this project，the author investigates a real-life problem regarding the reduction of traffic congestion in a very busy boulevard。The author establishes a model using graph theory，and then proposes a solution via the removal of edges in order to decrease interruptions。The ideas and presentations are both good。That being said，the model is a bit oversimplified to be useful in practical traffic control.