Designing PUV Transportation Routes for Cleared Areas in Marawi City Using Graph Theory

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ABSTRACT

This paper presents a methodology for establishing transportation routes for public utility vehicles (PUVs) within the cleared areas of Marawi City, addressing key challenges faced by local residents. By applying fundamental concepts of graph theory, we construct a graphical representation of the city's cleared zones, which serves as the basis for identifying subgraphs that represent optimal transportation routes. The findings of this study provide a potential framework for local government agencies to implement transportation routes that prioritize passenger safety, travel efficiency, and optimal distance.

Keywords: Graph; Subgraph; Graph Labelling; Directed Graph; Marawi City

I. INTRODUCTION

1.1 The Islamic City of Marawi

Marawi City, the capital of Lanao del Sur in the Philippines, is often referred to as the *Islamic City of Marawi* due to its predominantly Muslim population. The inhabitants, known as *Meranaws* or "people of the lake," derive their name from the city's location on the northern shores of Lake *Lanao*, where the *Agus* River begins. Marawi spans a total land area of 8,755 hectares (21,630 acres) [4,6] and sits at an elevation of approximately 2,300 feet along the lake [6]. The city's high altitude, coupled with frequent rain throughout the year, results in cooler temperatures compared to other parts of the country.

Historically, Marawi was originally called *Dansalan* when it was founded in 1639 by Spanish forces from Iligan City. These forces aimed to conquer the Lake Lanao area but were thwarted by thousands of Meranaw warriors, forcing the Spaniards to retreat after an unsuccessful campaign. They only returned in the late 19th century during the conquest of the Sultanate of Maguindanao, but their efforts were once again halted when the Americans arrived in 1900 [6]. Figure 1 provides a drone view of Marawi City and Lake Lanao, captured by George Isaac Asibal and uploaded on YouTube on August 3, 2015.

Figure 1. Drone View of Marawi City and Lake Lanao

Marawi is also home to the Mindanao State University (MSU) Main Campus, established on September 1, 1961, through Republic Act 1387, as amended. MSU was created with the mandate to foster integration among Muslims, Christians, and *Lumads*, and to serve as a government instrument for achieving peace and sustainable development in Southern Philippines. As the largest state university in Mindanao and second in size only to the University of the Philippines, MSU

Figure 2. (left) Philippine Fighter Jet; (right) An Airstrike in Marawi

operates 11 autonomous campuses across strategic locations in the region.

On May 23, 2017, ISIS-affiliated Maute and Abu Sayyaf terrorist groups besieged Marawi City under the leadership of Isnilon Hapilon, one of the world's most wanted terrorists. Their attempt to establish an ISIS stronghold in Southeast Asia led to an intense battle with the Armed Forces of the Philippines. The following day, President Rodrigo Roa Duterte declared martial law across Mindanao, marking the beginning of what would become the longest and deadliest urban warfare in the Philippines' modern history. The conflict saw the deployment of newly-acquired high-powered weapons, artillery, and airstrikes, resulting in significant devastation. Residents of Marawi were forced to flee to evacuation centers in nearby provinces. Figure 2, sourced from Google, shows images that depict the everyday situation in Marawi during the height of the war.

The conflict officially ended on October 17, 2017, when President Duterte declared the liberation of Marawi following the death of Hapilon and other terrorist leaders in a military assault. The war, which lasted nearly five months, left deep scars on the city and its residents. While some residents were allowed to return to their homes in selected cleared barangays, those from the commercial and financial districts—the main battle area—were left facing a bleak future amid the ruins. Among the numerous challenges faced by residents of the cleared areas is the lack of access to basic necessities such as food and water. With no functioning markets in the city and a dwindling number of relief operations, residents are forced to travel to nearby municipalities like Marantao, 19.2 kilometers away, or Saguiaran, 9.9 kilometers away. However, the limited availability of public transportation and unregulated fares have made even these journeys difficult. To address this pressing issue, this study proposes the establishment of a public utility vehicle (PUV) transportation route using basic concepts from Graph Theory as its framework.

1.2 Objectives of the study

This paper seeks to achieve the following objectives:

1. To construct a graphical representation of the cleared areas in Marawi City; and
2. To derive subgraphs that represent the proposed public utility vehicle (PUV) transportation routes.

1.3 Significance of the study

This paper will be beneficial to the following:

Local Government Units. The research provides valuable insights for the local government of Marawi, offering guidance on the proper implementation of public utility vehicle (PUV) transportation routes. The study considers important factors such as passenger destinations, safety, and travel distance to ensure an efficient and secure transportation system.

Residents of Marawi. The study aims to address the challenges faced by Marawi residents, particularly the scarcity of public transportation options and the issue of unregulated transportation fares, by proposing well-structured PUV routes.

National Government. This research can serve as a reference for the national government in implementing similar transportation projects in other cities or municipalities across the Philippines facing similar transportation issues.

II. METHODS AND MATERIALS

2.1 Brief Discussion on Graph Theory

In the early 18th century, the city of Königsberg was divided by the Pregel River, which encircled an island before splitting into two branches. Seven bridges connected four distinct landmasses, as shown in Figure 3. The citizens of Königsberg sought a way to walk through the city by crossing each bridge exactly once and returning to the starting point, but none could find a solution, regardless of where they began. This led to the emergence of a historically significant mathematical problem known as the **Seven Bridges of Königsberg**.

In 1736, Swiss mathematician Leonhard Euler (1707–1783) demonstrated that it was, in fact, impossible to devise such a path. His analysis of this problem laid the foundation for the mathematical discipline now known as graph theory.

Graph theory is commonly defined today as the study of graphs, which are mathematical structures used to model relationships between objects. A graph consists of vertices (also called nodes or points), which are connected by edges (also known as arcs or lines). Graphs are a fundamental focus of discrete mathematics and have a wide range of applications in various fields.

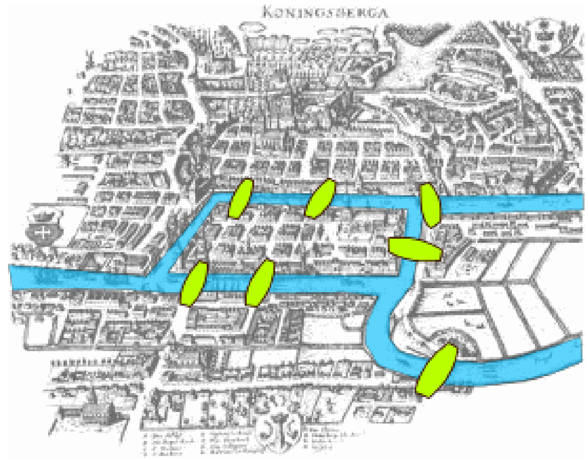

Figure 3. Map of Königsberg in Euler's time [7]

2.2 Definition of Terms

The following basic concepts in graph theory are utilized in obtaining the results of this paper:

Definition 1.[1] A **graph** G consists of a finite nonempty set V of objects called **vertices** (the singular is **vertex**) and a set E of 2-ekement subsets of V called **edges**. The sets V and E are the **vertex set** and **edge set** of G, respectively. So a graph G is an ordered pair of two sets V and E. For this reason, we write $G = (V, E)$.

Definition 2. [2] A graph H is called a **subgraph** of a graph G, written $H \subseteq G$, if $V(H) \subseteq V(G)$ and $E(H) \subseteq E(G)$.

Example 1. The figure below shows a graph and its subgraph:

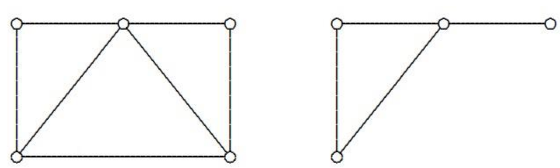

Figure 4. (left) Graph *G*; (right) Subgraph *H* of *G*

Definition 3. [2] Given a graph $G = (V, E)$, a **vertex labeling** is a function of V to a set of labels. A graph with such a function defined is called a **vertex-labeled graph**. Likewise, an **edge labeling** is a function of E to a set of labels. In this case, the graph is called an **edge-labeled graph**. When the edge labels are members of an ordered set (e.g., the real numbers), it may be called a **weighted graph**.

Example 2. The figures below represent an edge-labeled graph and a vertex-labeled graph:

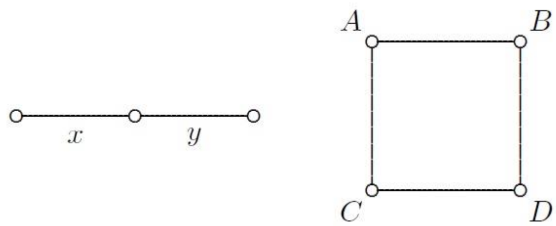

Figure 5. (left) an edge-labeled graph; (right) a vertex-labeled graph

Definition 4. [5] A **directed graph** is a graph $G = (V, E)$, where the $E(G)$ is a set of ordered pair elements of $V(G)$.

Example 3. The following is an example of a directed graph:

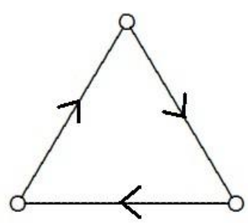

Figure 6. A Directed Graph

In addition to these formal definitions, other common terms in graph theory are also used. A **trail** from vertex v to vertex w is a walk from v to w that does not repeat any edge. A **path** from v to w is a trail that does not repeat any vertex. A **closed walk** is a walk that starts and ends at the same vertex. A **circuit** is a closed walk that contains at least one edge but no repeated edge. In all these cases, v and w are distinct vertices of a graph G.

For more detailed discussions on graph theory, the reader may refer to the books by Chartrand and Zhang [1], and Harary [3].

III. RESULTS AND DISCUSSION

Before presenting the results of this paper, it is essential to understand that after the war, the area of Marawi City can be classified into three categories, as depicted in Figure 7.

1. **Main Battle Area:** This refers to the region where intense fighting between the military troops and terrorist groups occurred. Due to heavy exchanges of fire and aerial bombardment, this area sustained extensive damage. Previously, this part of Marawi City was the commercial district, housing schools, markets, restaurants, parks, banks, and several government-owned establishments. At present, the military is still conducting clearing operations in this zone to remove possible unexploded ordnance and traps, a process expected to continue for at least another year.

2. **Cleared Area:** This section of the city suffered only minor damage, mostly from stray bullets during the height of the conflict. After several weeks of clearing and cleaning operations by the military and civilian volunteers, residents in this area, after fulfilling requirements set by the military, were permitted to return to their homes.

3. **Area of Mindanao State University (MSU) – Main Campus:** When the conflict between the military and terrorists erupted on May 23, 2017, the University administration promptly suspended all student activities and ordered the entire MSU security force to secure all entry points to the campus. Through coordinated efforts between MSU officials and local and provincial government units, faculty members, staff, and students were safely transported to Iligan City the following day. On the fifth day of the conflict, a Marine Battalion arrived on campus and established its first command center at the University Gymnasium. Remarkably, despite the war occurring less than 5 km away, MSU remained open, with regular office functions continuing. In August, MSU managed to open the first semester of the academic year 2017–2018, with more than 9,000 students enrolled.

Figure 7. Satellite View of Marawi City from Google Map

As noted earlier, residents in the cleared area urgently need regular public transportation vehicles to travel to nearby municipalities with available markets. Additionally, MSU students residing in the cleared area require transportation for safe transit to and from the campus gate.

The authors identified eleven (11) strategic locations that could serve as PUV (Public Utility Vehicle) stops:

1. MSU Gate
2. Crossing at Sarimanok Road
3. "Zero Kilometer" landmark
4. Amai Pakpak Medical Center (APMC)
5. Philippine Muslim Teachers College (PMTC)
6. City Hall
7. Barangay Dayawan (commonly known as "Tuca")
8. Matampay
9. Krystal Function Hall
10. Shell Gas Station
11. Mapandi Memorial College

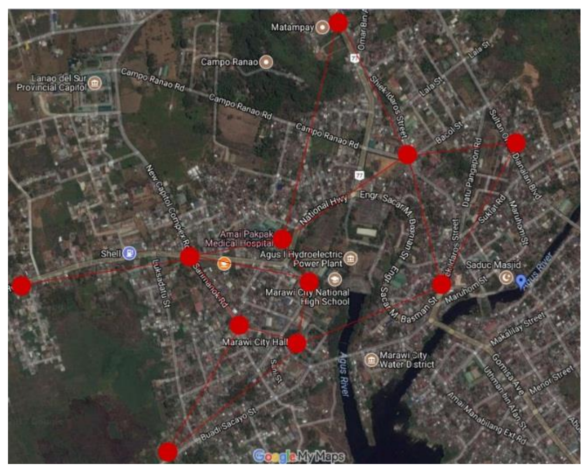

Figure 8. Suggested PUV Stops in the Cleared Area

These locations are illustrated in Figure 8. The rationale behind selecting these areas is twofold: they provide easy access to nearby communities or barangays, and they are familiar to the residents.

- For residents traveling to the Municipality of Marantao, a terminal is located near the MSU gate. Terminals for farther destinations, such as Cotabato, General Santos, and Davao, are also available in Marantao.

- Similarly, Matampay serves as a terminal for those traveling to Saguiaran, while additional transportation options to Iligan City and Cagayan de Oro City are available in Saguiaran.

When we treat these proposed PUV stops as vertices and the roads connecting them as edges, the result is a graph, shown in Figure 8, with labeled vertices representing the PUV stops.

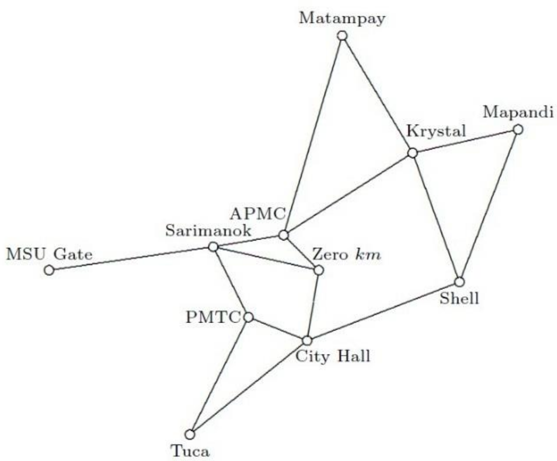

Figure 9. Graph of the PUV Stops (Graph *G*)

The graph G in Figure 9 serves as the basis for determining three transportation routes:

1. A route for individuals traveling to and from the MSU gate, particularly MSU students and residents heading to Marantao.
2. A route for those traveling to and from Matampay, primarily residents traveling to Saguiaran.
3. A route for those traveling to and from Barangay Dayawan (Tuca), a more distant barangay in Marawi City.

To obtain these three routes, three subgraphs of graph G are identified.

Result 1. The first suggested route is the walk given by:

MSU Gate-Sarimanok-zero*km*-APMC-Krystal-Shell-City Hall-PMTC-Sarimanok-MSU Gate

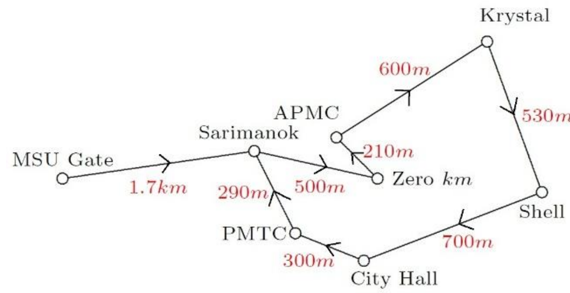

Figure 10. Route Number 1 (Subgraph *H*)

This route, illustrated in Figure 10 as Subgraph H, is intended for residents of the cleared area who wish to travel to and from the MSU gate. The vertices in Subgraph H are labeled according to the PUV stops they represent in Figure 8, and the edges connecting them are labeled based on the actual distance of the shortest available roads from the map of Marawi City. The total travel distance for completing a round trip on this route is 6.53 kilometers.

Result 2. The second suggested route is the circuit given by:

Matampay-APMC-Zero*km*-City Hall-Shell-Mapandi-Krystal-Matampay

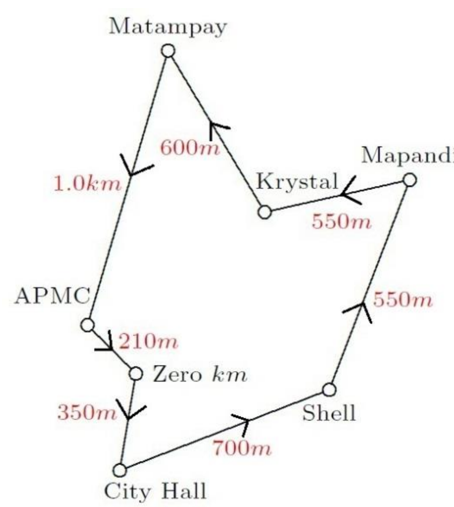

Figure 11. Route Number 2 (Subgraph *I*)

This route is depicted in Figure 11 as Subgraph I. It is designed for residents of the cleared area who wish to travel to and from Matampay. Like Subgraph H, the vertices in Subgraph I represent the PUV stops shown in Figure 8, and the edges are labeled based on the actual distances of the shortest available roads from the map of Marawi City. The total travel distance for a round trip on this route is 3.96 kilometers.

Result 3. The third suggested route is the circuit given by:

Tuca-City Hall-Shell-Krystal-APMC-Sarimanok-PMTC-Tuca

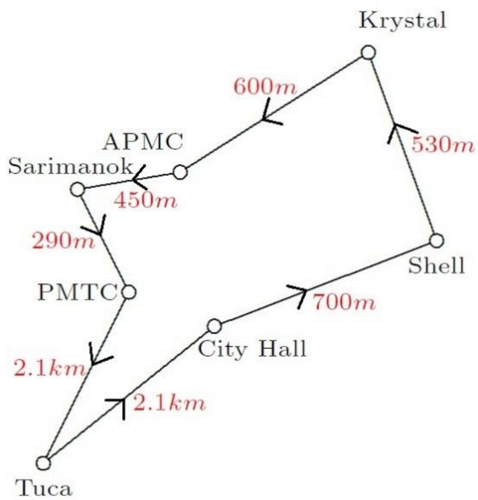

Figure 12. Route Number 3 (Subgraph *J*)

This final route is represented in Figure 12 as Subgraph J. It is intended for residents of the secluded Barangay Dayawan (commonly known as Tuca) who need transportation to and from the city center. This route is especially useful for those traveling from Brgy. Dayawan who wish to reach either the MSU gate or Matampay by using connecting rides. As with the previous subgraphs, the vertices in Subgraph J are labeled to correspond with the PUV stops in Figure 8, and the edges reflect the actual distances on the map of Marawi City. The total travel distance for this round trip is 6.77 kilometers.

IV. CONCLUSIONS AND RECOMMENDATIONS

The subgraphs H, I and J, which are both vertex-labeled and edge-labeled graphs, serve as examples of labeled graphs. Since the edge labels in the three subgraphs are real numbers representing distances, they also qualify as weighted graphs. Subgraph H represents a walk (though not a closed walk) that starts and ends at the same vertex, while subgraphs I and J are circuits, as they begin and conclude at the same vertex without repeating an edge. Moreover, since all three subgraphs represent transportation routes with a specific direction of travel, they are classified as directed graphs.

The transportation routes proposed in this paper offer practical solutions that can be used by the local government of Marawi City to establish temporary routes for Public Utility Vehicles (PUVs). These routes are designed around significant landmarks in Marawi City, ensuring that residents can easily identify where PUVs will stop and pass through. This is particularly important in the current climate, where safety concerns—such as alleged abductions—have heightened anxiety in the city. By deploying security personnel or police forces to these key landmarks, the local government could enhance the safety and well-being of the residents. Additionally, the well-defined distances between landmarks provide the local government with a tool to address the issue of unregulated and excessive transportation fees. Drivers can be instructed to charge fares that are proportionate to the total travel distance along each route.

The authors recommend that future researchers explore further applications of graph theory to solve other transportation-related issues, such as traffic congestion in Marawi City. Additionally, graph theory could be applied in the reconstruction and redevelopment efforts of the main battle area of Marawi City, offering another avenue for meaningful research.

V. ACKNOWLEDGEMENTS

This paper originated as part of a group project during the Modified CHED Second Generation Faculty Training for the Teaching of the New General Education Core Courses, held at the University of San Jose—Recoletos in Cebu City on November 11, 18, 25, and December 2, 9 in 2017, and January 13, 27 in 2018. The authors would like to acknowledge the contributions of their fellow group members: Ms. Marife C. Carreon from the University of Cebu, Mr. Jhun R. Padayao from Cebu Eastern College, and Mr. John Dave Ramos from St. Cecilia's College, Cebu, Inc. Their collaboration were invaluable to the completion of this paper.

This paper is dedicated to the victims of the Marawi Siege.

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