A Proposed Optimization Algorithm for Solving CCTV Camera Placement

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ABSTRACT

The installation of CCTV cameras monitoring the street sections of one of the most visited areas of Manila may serve as deterrence against theft, crime, abduction, and even act of lasciviousness. Furthermore, the redundant orientations of some of the units in the system were recognized as possible inhibitors of the efficiency of the local surveillance system. In line with this, the study proposed a model for CCTV camera placement in Intramuros by representing the community as a graph in a 2-dimensional space. The paper presents a two-phase approach in determining the best placements of CCTV cameras. Phase I took care of the ideal installation spots as a set-covering problem while Phase II identified the optimal CCTV orientation using the Proposed algorithm. In Phase I, a binary integer programming model was formulated and solved using the data solver function of Microsoft Excel. The designed algorithm in Phase II was based on greedy heuristics utilizing the results in Phase I to identify the optimal orientation of the CCTV units. Findings suggest that out of the seventeen candidate locations, nine of them are optimal for CCTV installation. A total of twenty-three CCTV units are required to cover all the entry and exit points of the streets in district 5 of Intramuros. The proposed algorithm produced two optimal solutions A and B. Comparison with the existing CCTV system in the district and discussions on each optimal installation suggested that result B is better than A. Recommendations on the results of the study were addressed to the authorities of district 5 for immediate implementation.

Keywords: Camera placement, CCTV, Greedy algorithm, optimization, set-covering.

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I. INTRODUCTION

The prevalence of closed-circuit television cameras, commonly known as CCTV, has significantly increased because of its vital role in deterring crime. The presence of CCTV cameras in both private and public places may increase safety, security, provide footage which can be utilized by the law enforcers as strong evidence against the offenders. Initially developed to learn more about weapons during World War II [1], these surveillance cameras are now commonly used to deter crimes and prevent perpetrators from even instigating unwanted behavior [2]. Comprehensive studies of CCTVs and innovations concerning camera and wireless technology prompted the expansion of its spectrum of utilization [3]. This includes but is not limited to traffic and road monitoring, medical diagnosis, behavioral research, and marketing intelligence [4]. As a result, several types of CCTVs now exist in the world, with distinctive features that correspond to the user's needs.

Video surveillance cameras have become an integral part of modern society. According to [5] in his report of a study conducted by the research website Comparitech, 770 million units of public-used CCTV cameras are already installed across the globe as of 2019. This figure does not yet include indoor units that are used to keep an eye on the interiors of private establishments, and it represents how critical CCTV technology in these days. The same study showed how China dominates the world when it comes to public surveillance, constituting 54 percent of the stated global quantity. While progressive metropolises of the global race toward being smart cities [6], surveillance technology is revolutionized as it plays a vital role in the development of systems that will ensure the city's safety and security [7].

Mass surveillance and a greater presence of security cameras, as we are already seeing in China, could spread to other countries [3]. An increase in the utilization of video surveillance systems in the Philippines is evident nowadays and this growth is expected to continue for years to come [8]. The demand for safety and security in the country arose due to growing insurrection and terrorist activities [9], and the surging of construction projects owing to the government's "Build, Build, Build" program. Nowadays, surveillance cameras capable of facial recognition [10] and plate number identification [11] are currently being utilized throughout the streets and roads of Manila. The country's capital city makes use of these advanced CCTVs to further guarantee the safety of the citizens and to be a primary tool for the execution of a no-contact apprehension policy for traffic violations.

One of the highlight destinations to visit when passing by the municipality of Manila is the historical Walled City of Intramuros. Strategically located in the center of the city, it is nearby most of the capital's major landmarks. The three main public museums of the country, the National Museum of Anthropology, the National Museum of Fine Arts, and the National Museum of Natural History, are all just within walking distance from Intramuros. It is also adjacent to one of the largest national parks in the country, the Rizal Park, which plays a significant role in shaping the history of the Philippines. Furthermore, it is surrounded by several establishments that are fundamental to the city and the country such as the Manila City Hall, the Manila Hotel, the Manila Central Post Office, and more. On the other hand, the interior region of Intramuros houses numerous tourist destination spots, educational institutions, churches, businesses, and structures as well, that are economically, historically, socially, and spiritually important, not just to the Manileños but to all Filipinos alike.

It is obvious that a comprehensive surveillance network that watches over the Walled City of Intramuros is especially beneficial to the constituents and visitors of the heritage site as major concentrations of Manila's population and tourist activities take place around the area. This is currently being observed within the premises of district 5, a community that exists inside the historic walls, using surveillance cameras installed in different locations around the neighborhood. District 5 is located in the southern part of Intramuros and includes the Pamantasan ng Lungsod ng Maynila, the establishment of the Department of Labor and Employment, and the Manila Bulletin Corporation as some of the major components within their authoritative region. There is a total of nine main streets that exist across the area of the barangay that are within the walls, divided into segments by seventeen street intersections. The mentioned administrative division has a CCTV system centered at the barangay hall that monitors the movements of the people and automobiles that traverse the community.

The researchers of this study are frequently navigating through the streets of district 5 inside Intramuros. Upon careful observation, some of the street sections of the barangay that are within the walls of Intramuros are not included in the community surveillance. Specifically, the absence of a surveillance unit to watch over the street section that is on the rear gates of the aforementioned university has become a particular concern for the researchers. Moreover, some of the installed CCTV cameras in district 5 are noticed to be facing each other on monitoring the same street section. Although the CCTV cameras used in the district were designed to withstand varying and changing environmental conditions, some of those that surveil the streets are now in observable rustic conditions.

The reduction and alleviation of possible complications in the current CCTV system of the district will prompt the efficiency of local surveillance. As such, the recognition that there must be refinement and modification in the current CCTV system of the community set the idea of this research paper. Today, various mathematical methods practically provide solutions to societal problems and so does the problem of optimal camera placement. In an effort to improve the CCV system of district 5, the researchers converted the problem into an IP model and utilized Microsoft Excel solver and QM for windows to solve the model. Approaching the problem of determining optimal CCTV camera placement mathematically would provide theoretical results that could serve as a fundamental basis when planning for a surveillance network. The solutions would be beneficial to the city government's campaign against crime and other real-world problems.

A. Statement of the Problem

Having CCTV cameras installed around the community is of extreme help in maintaining peace and order, but intelligent planning is necessary to maximize their efficiency. Installing the optimum number of CCT units at optimum spots. Determining the optimum number of CCTV units to be installed and their optimal placements in the streets will ensure optimal monitoring and promote cost-cutting in the city government. The researchers sought to optimize the placement and orientation of the CCTV units in the surveillance network of the 5th district of Manila. Specifically, this paper seeks answers to the following problems:

1. Where are the best installation spots for CCTV units in order to optically monitor all the entry and exit points of the streets of the 5th district of Manila?

2. What is the orientation of the CCTV units optimizing the installation needed to monitor the entry and exit points of the streets of the 5th district Manila?

3. What changes can be suggested for the current CCTV system in district 5 of Manila?

II. Literature Review

A. CCTV Camera in Crime Prevention

Camera surveillance using CCTV units can be considered as a technique of Situational Crime Prevention (SCP) which aims to strengthen formal surveillance on a specific location, thus increasing the criminal's perceived hazards of instigating crime and minimizing opportunities for crime to occur [12]. CCTV cameras enable users to watch over an area in real-time and record happenings in the vicinity which can then be reviewed later whenever the need to do so arises. As such, CCTV units can be regarded either as supplementary to security management or as a substitute for security personnel [13]. Submit your manuscript electronically for review.

International research about the efficiency of CCTV cameras in crime deterrence has increased through the years and as a result, the knowledge about the topic gradually developed. [14], assessed several distinct studies around the world which investigate the matter and concluded that there is indeed a linkage between the use of CCTV and a significant decrease in crime. Their analysis has revealed that the largest and most consistent effects of CCTV can be found in car park settings, which can be attributed to factors such as mediation of security personnel, improved lighting, posting signages, active monitoring, and excellent camera coverage. This implies that the presence of an effective CCTV system alone does not guarantee safety and security, hence, must be incorporated with other types of involvement. Meanwhile, archived CCTV recordings that remain accessible for investigation were associated with a substantial increase in

the possibility of solving most types of crimes [15]. Accordingly, this implies that CCTV technology can be employed not only as a crime mitigator but also as an investigative tool as well.

Even though local studies on the subject are limited, available sources emphasized the importance of CCTV networks in residential areas. Research journals from the Lyceum of the Philippines Batangas College of Criminology contained discussions about the status, common problems, and effectiveness of CCTV systems within the city. Manalo et al [16] collected insights from residents of Batangas and discovered that the installation of CCTV cameras helps in reducing the anxiety of citizens by stimulating a safer environment. [17] stressed in their study that CCTV cameras greatly assist in monitoring the people who go in and out of the community, making it easier to locate suspicious people on the streets. Meanwhile, CCTV is widely utilized as an investigative tool in solving various crimes in the Philippines. A notable case is when the host actor Vhong Navarro was beaten in 2014. Recorded CCTV footage of the events captured by cameras of the condominium supported Navarro's claims and became strong evidence to disregard the rape charge against him, penalizing the people who tried setting him up [18].

B. CCTV Placement Optimization

A higher quantity of CCTV cameras does not necessarily reduce the crime rate [5] however, additional interventions that correspond to video surveillance do. Aside from incorporating active policing, [19] also highlighted the importance of designing CCTV network operations in a manner that reinforces their preventive effect, which means that intelligent planning of installation is necessary. Strategic positioning of camera units within their target vicinity will increase their overall performance and minimize potential costs [20]. This demonstrates that research about camera modeling is continuously becoming more relevant in designing surveillance networks [21].

Since CCTV serves as additional "guards" that keep an eye on certain spots, some camera placement problems involve the use of traditional methods applied in the Art Gallery Problem (AGP). AGP is an optimization problem to find the least amount of security guards necessary to cover the interiors of an art gallery along with their best possible stations [22]. However, solutions to AGPs are highly theoretical and results may not be as effective when applied to real-life situations. Hence, situations that require highlighting practical constraints to maximize utility and efficiency of the camera units, or to minimize the total cost needed for the system installation, are shifted to have more realistic assumptions not in AGP [23].

Reference [23] gave an overview of the camera placement approaches that are being used by various studies in recent literature as shown in the flowchart in Fig. 1. According to them, the approach used by a typical camera placement problem can be summarized into four steps: Input, Prepare, Solve, and Output. The identification of camera specifications, task requirements, and the model environment are included in the initial steps described as Input stage. When the problem is going to be tackled in discrete solution space, discretization of parameters and the initially entered data is

added in the Prepare step. However, if the problem will be discussed in the continuous domain, [23] mentioned that it is not necessary to go through the preparation stage. The process will proceed to the Solve step, which includes the formulation of an optimization problem using the inputted task requirements and objectives. Finally, the Output stage is where the optimization problem is solved using appropriate techniques.
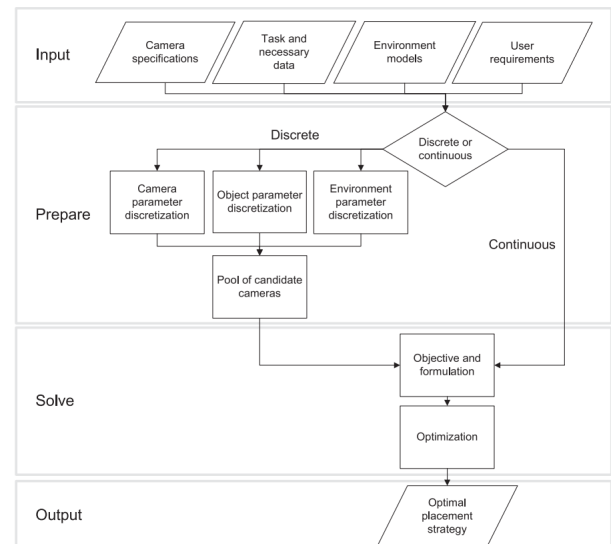

Fig. 1. Overview of Camera Placement Approaches. Note: Reprinted from "Recent Advances in Camera Planning for Large Area Surveillance: A Comprehensive Review" [23].

The same study by [23] classified camera placement problems into two categories based on the observed trend of studies included in their review. Max-Utility includes maximization of the utility of available units commonly faced when the problem is provided with a limited number of cameras. Min-Cost on the other hand minimizes the cost of system installation while providing adequate utility. In a Min-Cost formulation, all conditions assigned by the user and all the required regions are covered, such that the camera placement configuration has minimal costs. These problems can be represented as a set coverage problem, defined by [24] as:

Minimize $\sum_{i=1}^{N_{Cand}} e_i x_i$ such that $Ax \geq b$, and $x_i = 0,1$.

where e_i is the cost associated with the ith candidate camera and x_i is the binary decision variable that tells if the ith camera is selected from the N_{cand} candidates. The variable A represent a $N_{region} x N_{cand}$ matrix, where N_{region} denotes the total number of discretized regions. The ith column of A represents the coverage of all the regions by the ith camera. On the other hand, b is an N_{region} dimensional binary vector indicating the regions that need to be covered which will be specified by the end user.

Large-scale set coverage problems can utilize greedy algorithms to give approximations for optimum or near-optimum solutions [24]. By definition, a greedy algorithm is an approach used for problem-solving that consists of steps that instructs the user to select the best option that is available at the moment, for each iteration. In camera placements problems, it instructs users to enter one camera to the optimal set at each iteration, giving prioritizations based on the formulated set of rules. However, the algorithm does not stop

until all candidate cameras are processed, nor when there is an error committed, and hence may give optimal or nonoptimal approximations.

C. Linear Programming in Camera Placement

The advancement of mathematics and other disciplines that are closely related to it has become beneficial in solving problems in society. Although discoveries are deemed to be theoretical, scholars and academicians have developed disciplines to translate pieces of knowledge into what is practical. With models, practical issues and real-world problems can now be transformed into mathematical terms [25]. That a model is complete (i.e., models represent only the essential component of the system) also means that it can be approached as a framework with no unimportant details.

Meanwhile, a systematic approach to solving several problems with a set of linear constraints classifies to what is known as linear programming. Linear programming is a mathematical method that either minimizes or maximizes constraints such that the value of the objective function attains its optimum value. This method has applications in project management, urban planning, food and agriculture, the energy industry, and many more.

Linear programming is an Operations Research (OR) method and therefore, is subject to the three basic components [26]:

1. Decision variables that we seek to determine.
2. Objective (goal) that we need to optimize (maximize or minimize).
3. Constraints that the solution must satisfy.

Due to its significance in crime deterrence both internationally and locally, and its integration into the modern world, studies about CCTV are both timely and relevant. CCTV cameras are proven to be effective both as a crime-deterrent and as an investigative tool, and their effectiveness can be obtained and enhanced by external factors like active monitoring, incorporated policing, and security camera placement optimality. This study will focus on optimizing camera placement and aims to suggest a model of optimal CCTV positioning along the street sections of District 5, Intramuros, Manila.

Related studies that were reviewed by [23] and [14], considered different factors and utilized distinct methods and techniques in optimizing camera placement. In this study, the focus is on monitoring all the entry and exit points of the streets of district 5. The nature of the research problem, which includes identifying the best possible places to install CCTV cameras such that they cover all street sections with minimal cost, is under the Min-Cost category of camera placement problems. Therefore, the study is discussed by employing linear programming methods utilized in approximating set-covering problems.

The greedy algorithm can be used in finding the optimum and non-optimum solutions to a large-scale set covering problems [24]. In addition, the steps that are being used in greedy algorithms can be modified to design a specific flow of instructions that will suffice the requirements for a particular task. As such, the researchers utilized greedy heuristics in devising an algorithm that will identify optimal camera orientation.

III. METHODOLOGY

The researchers formulated an LP mathematical model to optimize the CCTV placement in District 5, Intramuros, Manila. This ensures effective surveillance and optimal coverage of the entry and exit points of the community's streets. The methodology is divided into two stages. These are Phase I and Phase II (a Proposed Algorithm).

A. Environment Modelling

Since the objective is limited only to monitoring the entry and exit points of the streets in the barangay, the researchers used a graphical approach to model the target environment. This is done to represent the elements of the target district more visible. Fig. 2 shows an example of a simple graph that can be created to model a community with six candidate CCTV installation spots and seven street sections that need surveillance.
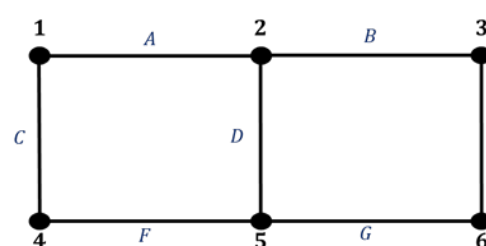

Fig. 2.Candidate installation spots and street sections in a sample graph.

In this study, the intersections of the streets of District 5, Intramuros, Manila were considered as candidate installation spots for the CCTV units. The researchers believed that it is only logical to place the CCTV units at street intersections so that each optimal installation spot can be possibly installed with multiple cameras faced in different directions, monitoring at least two distinct streets. Installing multiple cameras at the same installation spot to monitor different areas maximizes the available cables that are required to link the system and will therefore help minimize installation costs. The edges, on the other hand, represent the street sections of the roads that require monitoring at their entry and exit points.

Using the 2-D street map of the district collected from the ArcGIS application, the researchers defined a graph G whose vertices denote the possible installation spots for CCTV units around the district and whose edges represent the street sections of the community as shown in Fig. 3.
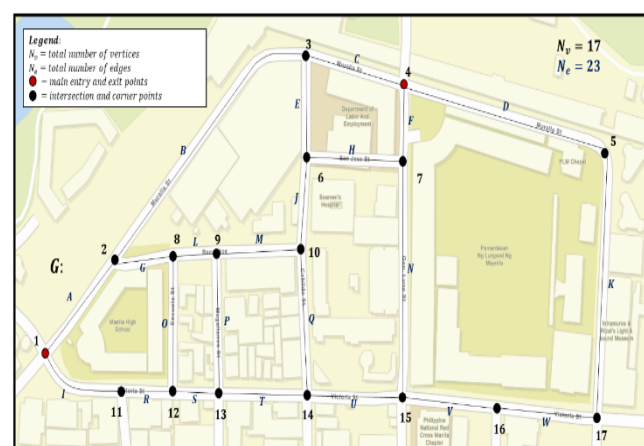

Fig. 3.Graph G in the 2D Street Map of District 5, Intramuros, Manila.

The red vertices on graph G are incident with an edge that represents a street that goes beyond the walled city. The researchers considered the red vertices as the main entry and exit points of the community and are regarded as vital spots for CCTV installation. Overall, there are a total of 17 candidate CCTV installation spots in District 5, and a total of 23 street sections that require surveillance.

This paper only concerns with the area of the district inside the walls of Intramuros, which makes the shape of the graph looks like an irregular trapezoid. From the initial graph G, the researchers created an equivalent graph H which aims to transform it into a simpler representation of the environment. The equivalent graph H consists of simple polygons and is isomorphic to G. This means that H connects the vertices of G using the same edges used to connect them in the original graph.

The transformation was made by flattening the edges of G, aligning some of its vertices in a way that they are leveled with adjacent vertices and some other minimal adjustments. Once again, the researchers did these with the assumption that the maximum range of CCTV units and the task of total coverage of the streets are not included as variables in the study, and thus will not have any effect on the results.

Subsequently, the researchers labeled each vertex and edge of graph H. The vertices are labeled with numbers 1-17 while the edges are labeled with roman alphabet from A to W. This is to give distinction to each element of graph G. The vertices and edges of the graph were both labeled from the uppermost left to the lowermost right of H. Afterwards, the vertices and edges of graph G were labeled as well based on how the vertices and edges of the final model environment graph H were named to relate its edges and vertices of to the streets and candidate installation spots of the district.

B. Phase I: Identifying Optimal CCTV Camera Installation Spots

The task of identifying the best locations to place the CCTV units in the district given a set of candidate installation spots was considered a set covering problem. Provided with a universal set $\bigcup$, a collection S of elements S_i of $\bigcup$, and a specified cost c_i for each S_i, set covering problems involve finding the optimal number of S_i's whose union covers the universal set while minimizing the total cost. In this study, the researchers defined $\bigcup$ as the universal set containing all the elements of the environment model graph H. Hence, the objective of Phase I is to find the minimum of cost sub-collection $X \subset S$ that covers all the vertices and edges in $\bigcup$.

1) Problem Formulation

The vertices of H are paired to the edges that are incident to them to connect the possible spots for CCTV installation to the streets they each can monitor. The researchers define these subsets of $\bigcup$ as S_i where the subscript i denotes the vertices of the graph H. The union of all the subsets S_i includes all the elements of the universal set $\bigcup$ and the collection of S_i is defined as S.

2) Cost Parameters

Each set S_i covers at least one element of $\bigcup$ and is associated with cost c_i such that $c_i > 0$. The researchers designated costs to the subsets of $\bigcup$ with the goal of distinguishing the main entry and exit points of the community from the rest of the candidate installation spots. This gives emphasis on monitoring the vital streets in the district that go in and out the walls of Intramuros. The subsets S_i that contain red vertices in the modeled environment graph H are assigned with a lower cost because they are incident with an edge representing a street going beyond the walled city.

3) Cover Parameters

The researchers represent the data about the candidate spots for CCTV installation and the streets they can each monitor using binary values. If the street j can be covered by a CCTV camera located at candidate spot i, then $y_{ij} = 1$, otherwise $y_{ij} = 0$, Hence, the cover parameter in this set-covering problem is represented by the following equation:

$$y_{ij} = \begin{cases} 1 \text{ if } i, j \in S_i \\ 0 \text{ otherwise} \end{cases}, \forall i. j \in \bigcup \tag{1}$$

4) Assumptions of Linear Programming

The Integer Programing is as a special type of Linear Programming Model. The IP model must satisfy the following properties:

Proportionality: Each decision variable's share to both the objective function and the set of constraints is proportional to its value. This means that the contribution of the decision variable x_i in the objective function also triples if x_i's value triples [26].

Additivity: The total contribution of all the decision variables in LP model is the sum of each decision variable's individual contributions [26].

Divisibility: The decision variables in an LP model can take nonnegative real numbers [27].

Certainty. The coefficient of each decision variable in an LP model is deterministic constant which does not change during the course of study [26].

5) Decision Variable

The researchers established a binary decision variable z_i to indicate if a camera is installed or not at the candidate CCTV installation spot denoted by i. If at least one camera is installed at location i, then $z_i = 1$, otherwise, $z_i = 0$. The decision variable for this is denoted by,

$$z_i = \begin{cases} 1 \text{ if a camera is installed at location } i \\ 0 \qquad\qquad\qquad\qquad\qquad \text{otherwise} \end{cases}, \text{ where } i = 1,2,3,\dots,17 \tag{2}$$

6) Objective Function

The goal is to minimize the number of CCTV units needed to monitor the entry and exit points of the streets of district 5 of Intramuros, Manila. Identifying the best spots for installation among the selected candidate locations allows the community to minimize the cost of monitoring different streets by installing multiple cameras in a single place. The objective function of the model was to minimize the total cost of the minimum number of subsets S_i covering all elements in the universal set $\bigcup$. The objective function for the model was

$$\text{Minimize } z = \sum_{i=1}^{17} c_i z_i \tag{3}$$

7) Constraints

The first constraint ascertains that for every edge j, there must be at least one camera installed at a vertex i incident with edge j to monitor street j. This ensures that there is at least one CCTV unit assigned for each street in the district.

Additionally, this enforces that each element in the universal $\cup$ must be covered. The first constraint is summarized by the inequality below.

$$\sum_{i=1}^{17} y_{ij} z_i \geq 1, \qquad (4)$$

for each street j, where j are labeled A to W.

The number of streets determines the number of constraints.

The second constraint restricts the values of the binary integer programming from being nonnegative and nonzero to guarantee that the objective function provides a nonnegative nonzero output. Moreover, it limits the value of the binary variable z_i to binary integers 0 and 1. The second constraint of this IP model is a binary nonnegativity constraint shown in (2).

8) The Final Mathematical Model

The final IP model for the research problems was formulated by combining the objective function and all the constraints obtained from the Labeled graph H that is equivalent (isomorphic) to graph G as shown in Fig. 4.
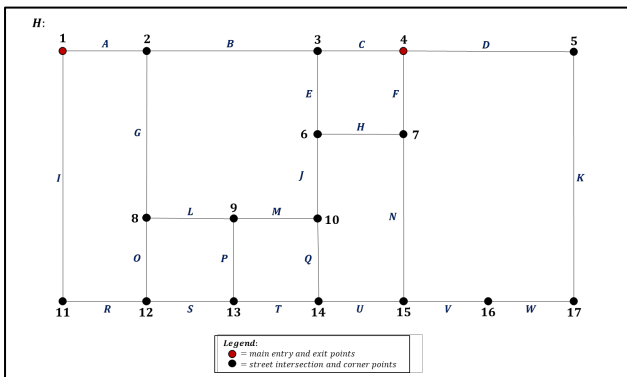
Fig. 4. Labeled Graph H (The Simple Graph Representation of District 5 Depicted in Graph G).

Final LP model for the Research Problems: Minimize

$$\sum_{i=1}^{17} c_i z_i$$

subject to the following constraints:

$$z_1 + z_2 \geq 1$$
$$z_2 + z_3 \geq 1$$
$$z_3 + z_4 \geq 1$$
$$z_4 + z_5 \geq 1$$
$$z_3 + z_6 \geq 1$$
$$z_4 + z_7 \geq 1$$
$$z_2 + z_8 \geq 1$$
$$z_6 + z_7 \geq 1$$
$$z_1 + z_{11} \geq 1$$
$$z_6 + z_{10} \geq 1$$
$$z_5 + z_{17} \geq 1$$
$$z_8 + z_9 \geq 1$$
$$z_9 + z_{10} \geq 1$$
$$z_7 + z_{15} \geq 1$$
$$z_8 + z_{12} \geq 1$$
$$z_9 + z_{13} \geq 1$$
$$z_{10} + z_{14} \geq 1$$
$$z_{11} + z_{12} \geq 1$$
$$z_{12} + z_{13} \geq 1$$

$$z_{13} + z_{14} \geq 1$$
$$z_{14} + z_{15} \geq 1$$
$$z_{15} + z_{16} \geq 1$$
$$z_{16} + z_{17} \geq 1$$
$$z_i \geq 0, \text{ for } i = 1,2,3,\dots,17$$

9) Solving the Binary Integer Program

The researchers used the Data Solver function in Microsoft Excel as a primary tool in solving the formulated binary integer program. MS Excel is a software created by Microsoft that can be used as a tool to organize, calculate, and format data using formulas that can be entered in a spreadsheet system. To check whether the software provided accurate results, the researchers used QM for Windows version 5. QM for Windows is a software tool used for mathematical analysis in a wide spectrum of applications such as Operations Management, Quantitative Methods, or Management Science. The Integer and Mixed Integer Programming function of QM for Windows was used to verify the solution to the set covering problem provided by MS Excel. The same LP model can also be solved by making use of SciPy and PuLP libraries in Python.

C. Phase II: Identifying Optimal CCTV Camera Orientation

The formulated binary integer programming model provides the best locations to install the CCTV cameras among the pre-determined candidate installation spots. After the ideal sites for CCTV installation are known, the quantity of the CCTV cameras required and the direction in which they should be directed are then identified. The researchers proposed a 4-step algorithm based on greedy heuristics that made use of the results gathered from the binary integer programming model with a general objective to determine the optimum orientation of CCTV units.
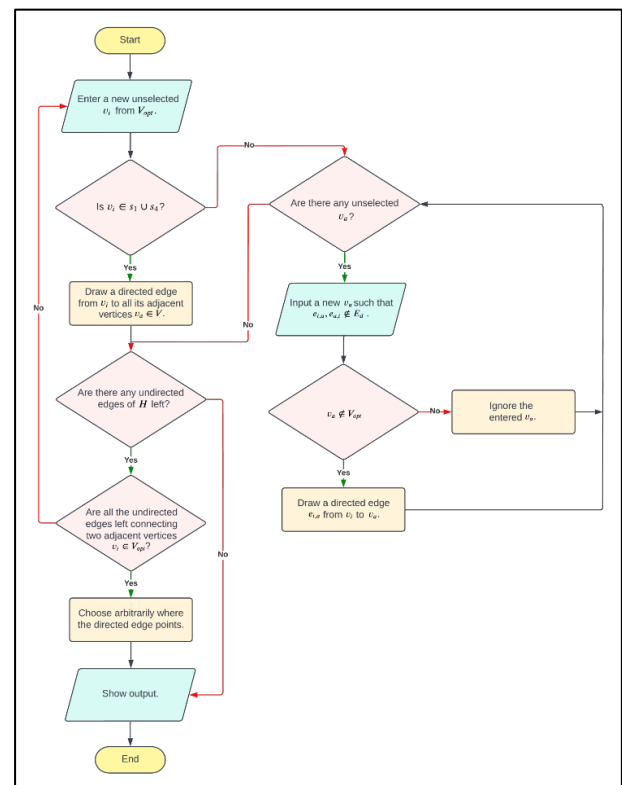

Fig. 5. Flowchart of the Proposed Algorithm for Optimizing CCTV Orientation.

The proponents of the study summarized the steps of the algorithm by creating a flowchart that represents the actions that need to be taken to determine where and how the CCTV cameras should be placed in the district. The flowchart is depicted in Fig. 5.

Intramuros is an urban-type district as it locates in the city of Manila. Being in the peripheral, two Intramuros' gates can be located around it. These gates serve as entrance and exit points in Intramuros for locals and tourists, making it a common walkway and driveway for individuals and vehicles. In total, nine streets connect establishments and people in the district listed below.

- Victoria Street
- Cabildo Street
- Muralla Street
- Gen. Luna Street
- San Jose Street
- Magallanes Street
- Escuella Street
- Recoletos Street
- Sta. Lucia Street

In 2020, the Philippine Statistics Authority reported that 982 people reside in the district. Aside from its residents, the barangay also houses a range of educational, commercial, and local establishments. The businesses that happen inside the barangay allow more activities to happen and hence, people move in and out of the area. A non-exhaustive list of places that can be considered landmarks in the barangay is as follows:

- Pamantasan ng Lungsod ng Maynila (PLM) (University of the City of Manila)
- Manila High School
- PNTC - Maritime Training Center
- Department of Labor and Employment (DOLE)
- AMOSUP Seamen's Hospital Manila
- Manila Bulletin Publishing Corporation

IV. MATERIALS

This study made use of the street map of the district 5 to model the environment mathematically. The researchers requested through a formal letter from the district officials a detailed map depicting the location and orientation of the CCTV units currently installed in the surveillance area. Figure 6 shows the placement and orientation of the CCTV cameras of the current CCTV system of the barangay that is located inside Intramuros using yellow triangle polygons.
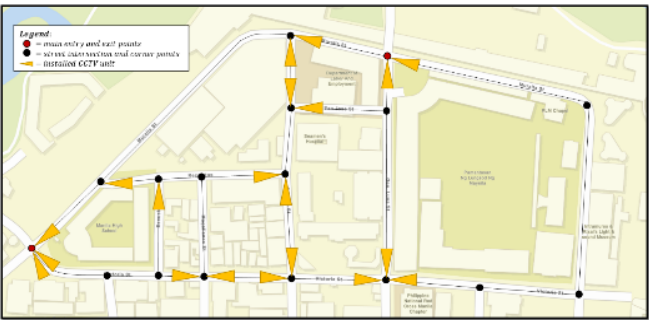

Fig. 6. The Current Monitoring System of District 5, Intramuros, Manila.

Furthermore, the researchers also generated a street map of District 5 from ArcGIS Pro version 2.9.32739. It served as a counter-reference from the original map provided by the district officials and the main map to serve the purpose of the study. Lastly, the researchers made use of Google Street View

to show the optimal placement of the CCTV units in real-life illustration.

V. RESULTS AND DISCUSSION

A. Phase I: Optimal CCTV Camera Installation Spots

The researchers defined the subsets S_i of the universal set $\cup$ as the pairing of the vertices of the environment model to the edges that are incident to them. The subsets S_i represent the set of each candidate CCTV installation spot and the respective street sections that they can possibly monitor. Fig. 7 shows the elements of each subset S_i.

Next, the subsets were given values representing their costs c_i. Since the main entry and exit points of the community are denoted by vertices 1 and 4, the subsets S_1 and S_4 are given a cost of 1, while the rest of the subsets are given a cost of 2. Installing cameras at the main entry and exit spots of the district is being prioritized, and the costs of each of the subsets S_i are shown in Fig. 8.

The determination of whether a candidate installation spot can cover a street section or not was done by utilizing the cover parameter formulated by the researchers. Fig. 9 shows the values of the binary variables y_{ij} in this study. The blank cells in the table represent a value of zero.

s_i	Vertex (Candidate Installation Spots)	Edges (Streets)
S_1	1	A, I
S_2	2	A, B, G
S_3	3	B, C, E
S_4	4	C, D, F
S_5	5	D, K
S_6	6	E, H, J
S_7	7	F, H, N
S_8	8	G, L , O
S_9	9	L, M, P
S_{10}	10	J, M, Q
S_{11}	11	I, R
S_{12}	12	O, R, S
S_{13}	13	P, S, T
S_{14}	14	Q, T, U
S_{15}	15	N, U, V
S_{16}	16	V, W
S_{17}	17	W, K

Fig. 7. Candidate camera location vs. Street Sections.

S_i	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	s_{11}	s_{12}	s_{13}	s_{14}	s_{15}	s_{16}	s_{17}
c_i	1	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2

Fig. 8. Subsets S_i's and their cost c_i.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A	1	1															
B		1	1														
C			1	1													
D				1	1												
E			1			1											
F				1			1										
G		1						1									
H						1	1										
I	1										1						
J						1				1							
K					1												1
L								1	1								
M									1	1							
N							1								1		
O								1				1					
P									1				1				
Q										1				1			
R											1	1					
S												1	1				
T													1	1			
U														1	1		
V															1	1	
W																1	1

Fig. 9. Binary Table of Camera Locations vs. Street Sections.

To determine the values of the decision variables z_i of the optimization problem, the values were entered into the Excel Solver. The data in the spreadsheet was arranged in such a way that the Excel solver output will be easily identified.

The screen capture in Fig. 4 shows that the solution row was left intentionally blank for the solver to display its decision on whether the variable z_i should be 1 or 0. The operator and the Right-Hand Side (RHS) columns indicate that each street should be covered by at least one CCTV camera. The "=SUMPRODUCT" formula is assigned to Z which returns the optimal summation of the products of each solution and its corresponding cost. The same formula was assigned to the cells of the Left-Hand Side (LHS) column displaying the number of optimal vertices that can monitor a distinct edge. LHS is the summation of the product of each cover parameter value on a street row with their respective solution values.

Fig. 10. Initial Solution Table in MS Excel.

The dialog box of the data solver was then filled out. The cells corresponding to the set objective, variables to be changed, and constraints were entered. Fig. 11 shows that U3 corresponds to the set objective in the data solver dialog box and ticked the option "Min." since this is a minimization problem. After which, the cells ranging from D3 to T3 were designated as variables to be changed in the linear program and were restricted to have binary values 1 or 0 only. The set covering constraints were then added and to complete the process, Simplex LP was selected as a solving method.

Fig. 11. Assigning Solver Parameters to the Data Solver.

The solver was successful in solving the binary integer programming and displayed the following results shown in Fig. 12. Based on the values of the solution cells, the best locations to install the CCTV cameras are at vertices 1, 2, 4, 6, 9, 12, 14, 15, and 17. Out of the seventeen initial candidate spots for optimal CCTV placement, nine were considered optimal with a total minimum cost of sixteen.

Fig. 12. Data Solver Results.

The values in the LHS column show that all the streets of the district can be covered by a single optimal camera location except for streets A and U. This means that both streets A and U are between two adjacent optimal CCTV installation spots, namely vertices 1, 2, and 14, 15, respectively.

To ensure the accuracy of the initial result, the researchers tested the data on another software (QM for Windows). The Integer and Mixed Integer Programming function of the software tool was utilized to verify the validity of the results of the MS Excel solver. The data were again entered into the program as well. Each decision variable z_i is binary for the nonnegativity binary restriction and the cost was entered as constant coefficients in the minimize row as shown in the screen capture in Fig. 13.

Fig. 13. Initial Solution Table in QM for Windows.

The solution of QM for Windows matched the results provided by the data solver of MS Excel. The decision variables for vertices 1, 2, 4, 6, 9, 12, 14, 15, and 17 were all assigned with a value of one and have a cumulative minimized cost of 16. The solution also signifies that CCTV

cameras should be installed at the said vertices to cover all the streets of the district.

Since the results of both software tools coincided, the researchers concluded that the union of the elements of the sub-collection

$$X = \{S_1, S_2, S_4, S_6, S_9, S_{12}, S_{14}, S_{15}, S_{17}\}$$

covers all the elements of the universal set $\bigcup$ in this set covering problem. The vertices in each of the subset S_i in X denote the optimal CCTV installation spots in the district, namely vertices 1, 2, 4, 6, 9, 12, 14, 15, and 17. These optimal CCTV installation spots are represented by red and yellow vertices in Fig. 14.
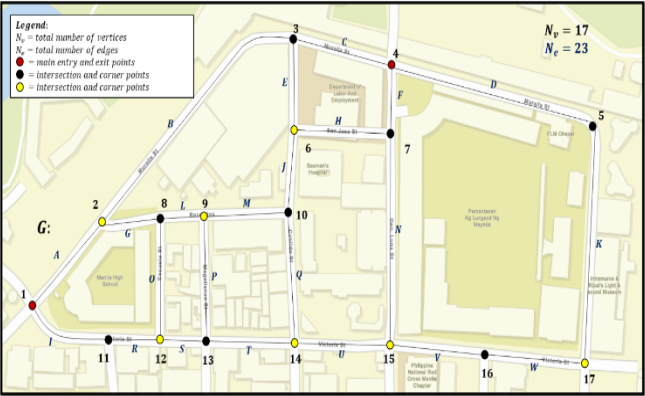

Fig. 14. Optimal CCTV Installation Spots on Graph G.

Likewise, the researchers also integrated the results into graph G by coloring the optimal CCTV locations with yellow. This is to determine what street intersections are being represented by the optimal CCTV spots. The main entry and exit points are optimal as well and are highlighted with red vertices as shown in Fig. 14.

Subsequently, the optimal vertices were tabulated as shown in a Fig 15. The streets x and y that intersect on the optimal CCTV installation spot, denoted by the edges that are incident to each v_i, were specified. Fig. 15 shows the street intersections of the district that are the optimal locations for CCTV installation as provided by the results.

Vertex	Street x	Street y
1	Victoria	Muralla
2	Recoletos	Muralla
4	Gen. Luna	Muralla
6	San Jose	Cabildo
9	Recoletos	Magallanes
12	Victoria	Escuela
14	Victoria	Cabildo
15	Victoria	Gen. Luna
17	Victoria	Sta. Lucia

Fig. 15. Optimal CCTV Installation Spots in District 5.

The street intersections were then carefully observed using images collected from Google Street Map. The local landmarks, other areas that can be monitored, and the possible benefits of CCTV installation on each of the optimal spot were given.

B. Vertex 1

Upon examination, installing CCTV cameras at the main entrance (vertex 1) enables the district to monitor the people and all vehicles passing through the district via Victoria street. Additionally, the people that come and go on the front premises of the Manila High School can be clearly recorded recognized as shown in Fig. 17. This will ensure the safety of

the faculty members, students, and other visitors of Manila High School. Some commercial establishments on the adjacent barangay can also benefit should a surveillance unit be installed in this spot.

Fig. 16. The Main Entry and Exit Points at the Muralla-Victoria Intersection [28].

Fig. 17. Manila High School as seen from Vertex 1 [29].

C. Vertex 2

On the other hand, the intersection of Recoletos and Muralla street denoted by optimal vertex 2 can be installed with units that can monitor an angle of Manila High School and some corner portions of the Manila Bulletin Publishing Corporation as shown in Fig. 18 on the previous page. The first-hand experiences of the researchers in the vicinity indicate that a CCTV camera monitoring the premises will be advantageous, especially at night. This spot of the barangay has minimal natural surveillance and receives low amounts of light from the street lamps due to the tall trees that are present nearby.

Fig. 18. Muralla-Recoletos Intersection [30].

D. Vertex 4

Vertex 4 represents the intersection of Muralla and Gen. Luna streets, where the façade of the Pamantasan ng Lungsod ng Maynila (PLM), as well as its main gates, are found. On the other side of the road is the establishment of the

Department of Labor and Employment (DOLE). An entry-exit point towards or away the walled city is also located in this area. It is a busy street intersection and is a high priority when it comes to community surveillance. Fig. 19 to 21 show the mentioned landmarks.

Fig. 19. Pamantasan ng Lungsod ng Maynila as seen from Vertex 4 [31].

Fig. 20. The Department of Labor and Employment as seen from Vertex 4 [32].

Fig. 21. The Main Entry and Exit Point at the Muralla-Gen. Luna Intersection [33].

E. Vertex 6

Meanwhile, vertex 6 is where the AMOSUP Hospital can be found. What seems to be a parking lot of trucks of Manila Bulletin corporation is also situated here. The intersection between the streets of San Jose and Cabildo is adjacent to the rear end of DOLE. A CCTV unit installed within the premises will enhance security and safety of patients, staff, and visitors of the said hospital. It will also complement the security guards in monitoring the parking lot. Figures 18-20 shows the view of the establishments as seen from the optimal CCTV installation spot 6.

Fig. 22. AMOSUP Hospital as seen from Vertex 6 [34].

Fig. 23. Manila Bulletin Carpark as seen from Vertex 6 [35].

Fig. 24. Rear Premises of DOLE as seen from Vertex 6 [36].

F. Vertex 9

The fifth optimal spot represented by vertex 9 can be placed with surveillance units to capture pedestrian crossing and automobile activities that occur in front of the PNTC Colleges -Maritime Training Center as shown in Fig. 26. An ATM Machine nearby Manila Bulletin's main entrance can also be monitored here. A local carpark can be seen along this intersection between Recoletos and Magallanes streets. In general, surveillance of this spot of the barangay can be beneficial to the employees of Manila Bulletin, the students of nearby educational establishments, and vehicle owners that patronize the parking lot.
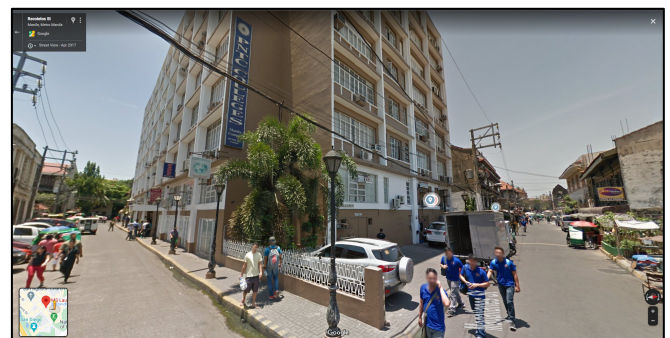

Fig. 25. PNTC Colleges - Maritime Training Center as seen from Vertex 9 [37].

Fig. 26. Manila Bulletin Entrance and a Local Carpark at the other side of the street [38].

G. Vertex 12

A busy street intersection can be found at the junction of Victoria and Escuella streets as shown in Fig. 27 and 28. Placing CCTV units in this location denoted by vertex 12 can help in monitoring the backside of the Manila High School, the community's Barangay Hall, and several commercial establishments such as the nearby 7-11 convenience store and the Intra Mall. Both the merchants and their customers will feel safeguarded when the area is being consistently monitored both by the barangay personnel and CCTV cameras.

Fig. 27. Barangay Hall and Rear of Manila High School at Victoria-Escuella Intersection [39].

Fig. 28. Commercial Establishments as seen Vertex 12 [40].

H. Vertex 14

Out of all the optimum installation locations that are indicated in the results, vertex 14 can be considered as one of the least busy. The nearby establishments that can be observed here are the rear part of the wedding venue and restaurant called Patio Victoria and a local parking lot. However, this street junction of Victoria and Cabildo is where the first branch of the historical Banco Español-Filipino de Isabel II once stood, commonly known today as the Bank of the Philippine Islands. This street can be installed with CCTV cameras to ensure the safety of the owner of the parked cars,

the tourists that will visit the historical site, and the people traversing this street crossing in general.

Fig. 29. The Rear of Patio Victoria as seen from Vertex 14 [41].

Fig. 30. The nearby Historical site where Banco Español de Isabel II once Stood [42].

I. Vertex 15

The intersection of Victoria and Gen. Luna streets is adjacent to a sidewalk beside Pamantasan ng Lungsod ng Maynila. The main entrance of Patio Victoria is in close proximity. The headquarters of the Philippine Red Cross – Manila Chapter is also nearby. Installing CCTV cameras in vertex 15 will grant the students, customers, employees, and volunteers of the said establishments an additional sense of protection. Fig. 31 and 32 display the street view in the optimal spot.

Fig. 31. Patio Victoria and PLM Sidewalk as seen from Vertex 15 [43].

Fig. 32. Philippine Red Cross and PLM as seen from Vertex 15 [44].

J. Vertex 17

Lastly, vertex 17 is the optimal CCTV installation spot situated at the intersection of Sta. Lucia and Victoria streets. The two streets that overlap in this location can be described as lengthy as shown in Fig. 33 and 34. This spot in the district can be installed with CCTV units that monitors the rear sections of the Pamantasan ng Lungsod ng Maynila. The Intramuros and Rizal Bagumbayan Light and Sound Museum are also located in this optimal installation spot. Surveillance of the specified location will be beneficial to museum guests and the adjacent university, as well as the people and vehicles that traverse the lengthy roads.

Fig. 33. Rear end of Pamantasan ng Lungsod ng Maynila as seen from Vertex 17 [45].

Fig. 34. Intramuros Light and Sound Museum as seen from Vertex 17 [46].

K. Phase II: Optimal CCTV Camera Orientation

The proposed algorithm was designed to determine where the CCTV cameras should be installed around the district. The following steps were based on greedy heuristics and are formulated based on the results found in Phase I. A detailed explanation of each step was provided to help understand how the system works.
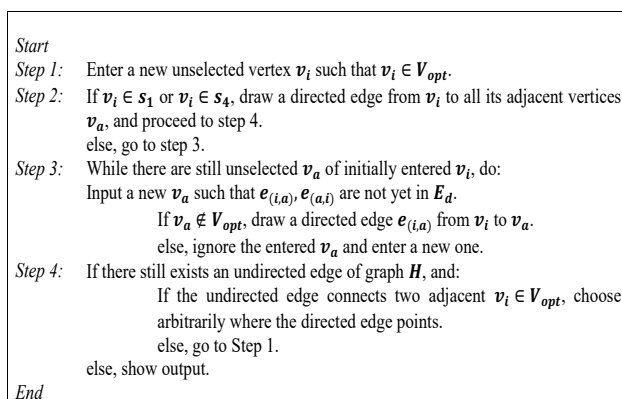
```
Start
Step 1:   Enter a new unselected vertex v_i such that v_i ∈ V_opt.
Step 2:   If v_i ∈ s_1 or v_i ∈ s_4, draw a directed edge from v_i to all its adjacent vertices
          v_a, and proceed to step 4.
          else, go to step 3.
Step 3:   While there are still unselected v_a of initially entered v_i, do:
          Input a new v_a such that e_(i,a), e_(a,i) are not yet in E_d.
                    If v_a ∉ V_opt, draw a directed edge e_(i,a) from v_i to v_a.
                    else, ignore the entered v_a and enter a new one.
Step 4:   If there still exists an undirected edge of graph H, and:
                    If the undirected edge connects two adjacent v_i ∈ V_opt, choose
                    arbitrarily where the directed edge points.
                    else, go to Step 1.
          else, show output.
End
```

Fig. 35. The Proposed algorithm to determine optimal CCTV Camera Orientation.

Initially, the researchers define set V to be the set of all the vertices v of the environment model graph H and edge set E. The set V has a subset V_{opt} containing the optimal vertices obtained from the results of the binary integer programming in Phase I. Let v_i be an arbitrary element of V_{opt} and v_a be any adjacent vertex of v_i such that $v_a \in V$. The goal of the algorithm is to create a directed graph of H such that its edges represent the optimal orientations of the CCTV units to be installed at $v_i \in V_{opt}$.

Let E_d be the set that stores all the directed edges formed by the algorithm and let $e_{i,a}$ be a directed edge from vertex v_i to v_a. Given the costs and the elements of each subset S_i of the universal set $\cup$ from Fig. 7 and 8, the steps for the algorithm include the following:

The first step of the algorithm picks a distinct ideal CCTV installation spot that is still unselected from the set of optimal vertices V_{opt}. This ensures that every iteration of the algorithm is unique and hence will not duplicate results for a single vertex v_i in V_{opt}.

The second step of the algorithm ensures that the main entry and exit points of the barangay are prioritized for CCTV surveillance. This step creates a directed edge to all of the edges adjacent to the red vertices representing the vital spots for CCTV monitoring regardless of the adjacent vertices' definitions. This means that whether $v_a \in V_{opt}$ or not, the algorithm enforces that the cameras should be installed in the main entry and exit points.

The third step of the algorithm is a while-if statement that appoints CCTV units to a street between the initially entered optimal installation location and the subsequently inputted adjacent, nonoptimal candidate spot. Additionally, it blocks the algorithm from connecting two adjacent optimal vertices $v_i \in V_{opt}$ in order to concentrate on assigning directed edges to adjacent nonoptimal vertices first.

The fourth step of the algorithm gives instructions on what to do if the case that optimal CCTV installation spots are adjacent to each other arises. Since they are optimal and can monitor similar streets, the choice goes to the officials of the barangay on weighing which installation spot turns out to be more beneficial to choose. Moreover, this step either returns the process to the initial stage of entering a new vertex $v_i \in V_{opt}$ or displays the final output of the algorithm.

Considering these steps, the researchers created a flowchart that summarizes the flow of instructions given by the algorithm as illustrated in Fig. 35. The algorithm was utilized to optimize the CCTV camera orientation.

The proposed algorithm was used to determine the optimal orientation of the CCTV cameras to be installed at each ideal installation spot. The algorithm aimed to create a directed graph of H where the direction of the edges denotes the orientation of the CCTV units to be placed on the ideal installation spots. The algorithm shows that each of the vertices $v_i \in V_{opt}$ must be entered exactly once and prepares a blank graph H to display the output.

The set V_{opt} is defined as a subset of the vertex set of H that containing the vertices v_i's representing the optimal CCTV camera installation spots in district 5, Intramuros, Manila. Therefore, the set

$$V_{opt} = \{1,2,4,6,9,12,14,15,17\}$$

Considering the main entry and exit points of the district first, the optimal vertices 1 and 4 are both elements of S_1 and $S4$, respectively. The second step of the algorithm suggested that these vertices should have directed edges stemming from them towards all of their adjacent vertices regardless of the status of v_a (whether optimal vertex or not).
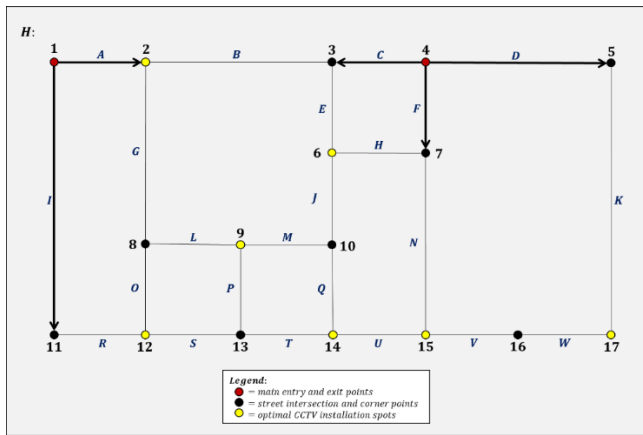

Fig. 36. Directed Edges in E_d for the Main Entry and Exit Points.

When any other optimal spot v_i is entered, the algorithm skips Step 2 and goes into the while-if loop of Step 3. Taking into account vertex 2, the algorithm instructs to draw a directed edge $e_{2,a}$ to all its adjacent nonoptimal vertices v_a. Therefore, entering vertex 2 adds the directed edges $e_{2,3}$ and $e_{2,8}$ to the edge set E_d. Next, if the vertex 6 is processed in the algorithm, step 2 will be skipped as well, and step 3 suggests that $e_{6,3}$, $e_{6,7}$, and $e_{6,10}$) should be included in E_d. The same scenario applies to vertices 9, 12, and 17 and Fig. 37 shows the unfinished directed graph of H.
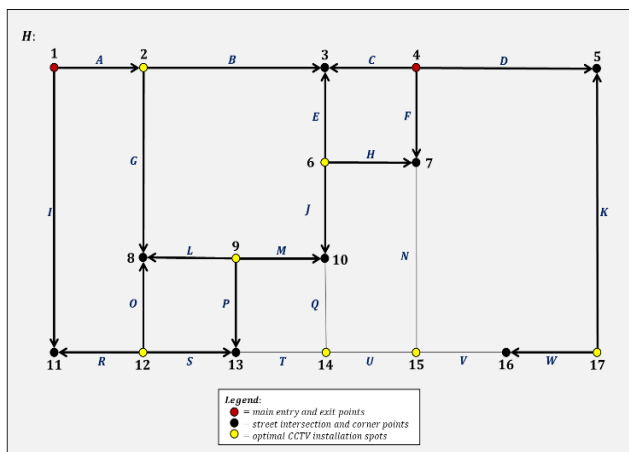

Fig. 37. Directed Edges in E_d for Optimal Vertices 1, 2, 4, 6, 9, 12, and 17.

The researchers intentionally left vertices 14 and 15 as the last inputs to be registered in the algorithm to discuss special cases when two optimal vertices are adjacent to each other, such that none of the two vertices is considered as main entry or exit points. Both vertices will skip Step 2 and go to Step 3 where the algorithm commands to create directed edges $e_{i,a}$ to all of their adjacent vertices except towards each other. After some reiterations of the while-if loop of Step 3, the edge between the two vertices remains undirected as shown in Fig. 38.
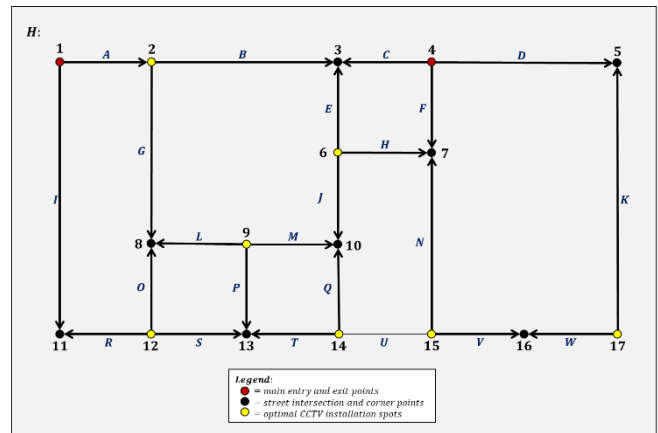

Fig. 38. A nearly-finished Directed Graph of H.

The proposed algorithm suggests that the user chooses arbitrarily where the directed edge between the two optimal vertices should be pointing at. This means that the decision on where to install the CCTV camera for monitoring the street between two ideal installation spots depends on the barangay officials that will plan the CCTV system of the community. As such, the researchers present two possible optimized models of CCTV placement for the barangay.

The first candidate optimized model developed by the researchers designated a directed edge from optimal vertex 14 to vertex 15. This means that the CCTV unit assigned to monitor street U is placed on the street intersection denoted by vertex 14 as shown in Fig. 40.
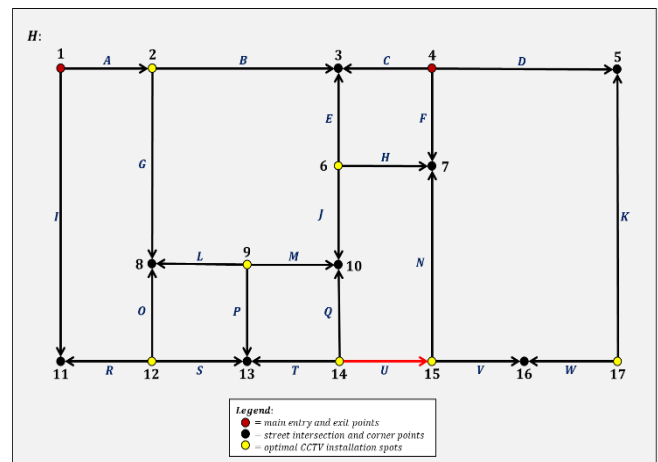

Fig. 39. Optimal CCTV Camera Orientation on Directed Graph H (A).

Installing a CCTV camera from vertex 14 to 15 ensures that the part of Victoria Street represented by edge U is being monitored with higher priority on the section near vertex 14. Based on the results in Phase I, vertex 14 is the intersection of Victoria Street and Cabildo Street. As mentioned in the discussion of Phase I, a car parking establishment exists nearby this street junction. Some studies, like those of [19], have shown that CCTV surveillance is highly effective in deterring crime around parking lots. This may be used as a deciding factor influencing the judgment of the district officials in choosing which optimal value should be used. Fig. 40 shows the first representation of how the CCTV units should be placed around district 5 based on this result.
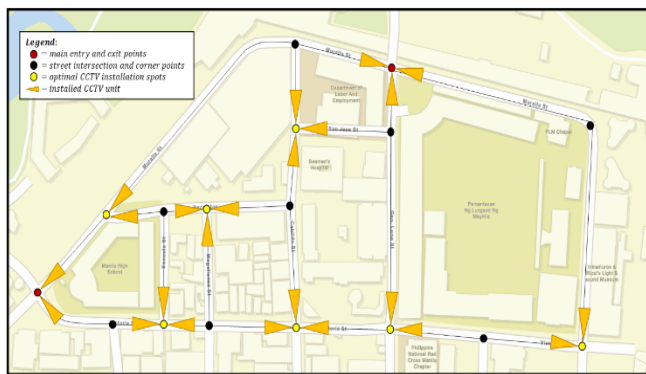
Fig. 40. The Optimal CCTV Camera Orientation (A).

The optimal amount of CCTV cameras needed to effectively monitor the entrance and exit points of the streets of District 5 can be seen in Fig. 40. A minimum of twenty-three CCTV camera units are necessary to cover all the street sections of the barangay, which is equivalent to the total number of edges in the modeled environment graph H. This means that each street segment represented by the edges is monitored by a single CCTV camera installed at optimal locations.

On the other hand, the second optimum solution was obtained by designating a directed edge from optimal vertices 15 to 14. This means that the CCTV unit assigned to monitor street U is placed on the street intersection denoted by vertex 15 as shown in Fig. 41. In the street map, vertex 15 represents the intersection of Victoria and Gen. Luna. Installing a CCTV camera on the said intersection puts a higher priority on the nearby premises discussed in Phase I.
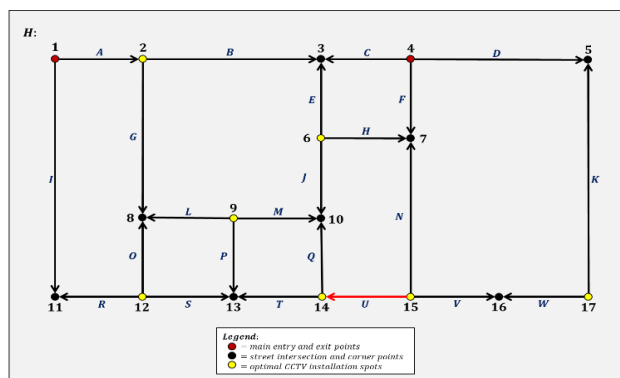

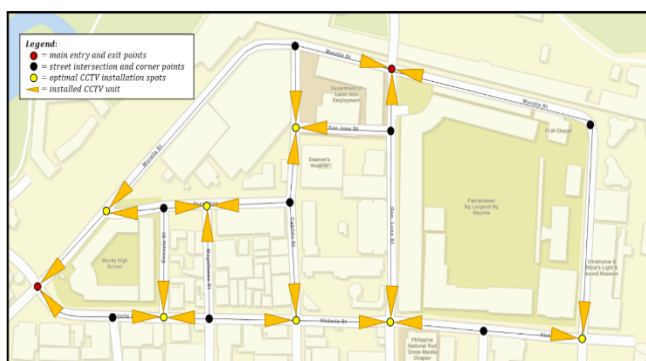Fig. 41. The Optimal CCTV Camera Orientation on Directed Graph H (B).

Fig. 42. The Optimal CCTV Camera Orientation (B).

Nevertheless, it should be noted that the sequence in which the optimal vertices v_is are entered into the algorithm does not have any restriction apart from that each vertex should be entered only once. This means that the users of the algorithm

may encounter the case where two optimal vertices are adjacent at the early stages of the process. However, step 3 will instruct to ignore such adjacent vertices first, and the if-if statement in Step 4 will guarantee that the program will not end until all of the edges of H become directed and stored in E_d.

L. Comparison to the Current CCTV System

Fig. 43 illustrates the deviations of the results of the study from the current existing CCTV system of the barangay in terms of CCTV installation spots. The diamond vertices signify the locations where the barangay installed their surveillance units while the circle vertices denote the optimal installation spots as identified by the study.

The current CCTV system of the district has its camera units installed in different street intersections around the community. This means that the study's environmental model, which treated the street junctions as the candidate optimal installation spots for CCTV units represented by the vertices, is aligned with what the barangay has initiated. The main entry and exit points of the district are being prioritized as well by the current system. Moreover, the barangay has already placed cameras at the street intersections denoted by optimal vertices 2, 6, 14, and 15, indicating that some of the currently installed units are already in their ideal place and orientation supported by the results of the study.
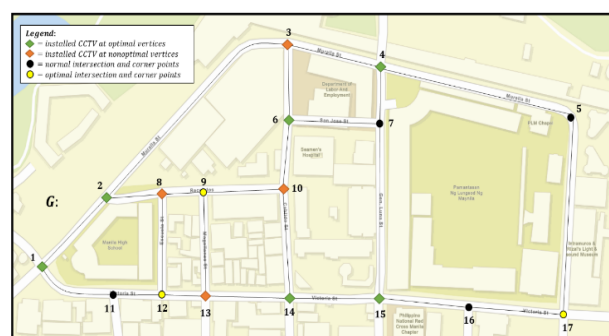

Fig. 43. Installation Spots of the Current CCTV System vs. the Results of Phase I.

As expected, variations of the current system from the results of this study are observed. The district has installed CCTV units at street intersections represented by vertices 3, 8, 10, and 13. The results of Phase I is indicative that the aforementioned vertices are not optimal locations to install CCTV cameras when the objective is to monitor the entry and exit points of streets. However, the researchers consider the possibility that the decision of the officials to install cameras in the said locations may be based on other factors not included in this paper.

M. Camera Orientation

Candidate Results A and B of the study show that the streets of the district can be covered by CCTV units. With much consideration to each CCTV camera's orientation, the researchers were able to optimize the direction of the surveillance units required to monitor every street around the district. This is guaranteed by the formulated algorithm. However, the current surveillance system of as seen in Fig. 35, does not monitor all streets bounded by the district. The street sections denoted by edges B, J, K, L, P, R, and W are not being surveilled in the present CCTV system. The same

figure illustrates a pair of six CCTV cameras that are positioned in such a way that two CCTV units are "mirroring" each other. The vertices that cover the same edge in the CCTV-system map of the district are vertices 3 & 6, 1 & 13, 10 & 14, 2 & 10, and 13 & 14.

Then, the orientation of the installed CCTV in relation to the proposed orientation of the CCTV units subject to the results of the study, were highlighted in Fig. 44 and Fig. 45. Similarities in the orientation of each CCTV unit are given importance; hence CCTV units are colored differently as shown in the illustrations' legends.

In Fig. 44, an inspection by observation through the provided visual representation confirms that only eleven CCTV units are similarly placed and set. The following edges denote the streets which are being monitored by CCTV cameras that are placed at the same installation spot and orientation indicated by Result A and the existing CCTV system of the district: A, D, E, F, G, H, J, N, Q, T, V. This means that more than half of the CCTV units currently placed within the district are already at their optimal spot and orientations based on Result A.

On the other hand, Fig. 45 shows 12 similarities. The following edges denote the streets which are being monitored by CCTV cameras that are placed at the same installation spot and orientation indicated by Result B and the existing CCTV system of the barangay: A, D, E, F, G, H, J, N, Q, T, U, V. This means that the current surveillance system of the community is one CCTV unit more similar to Result B than Result A of the study. Remember that both results of the study provide similar camera orientations installed at the same installation spots except for the one that lies in street U. The deviation between the two candidate results occurred because the current CCTV system of the barangay already includes a surveillance unit installed at vertex 15 directed towards vertex 14.
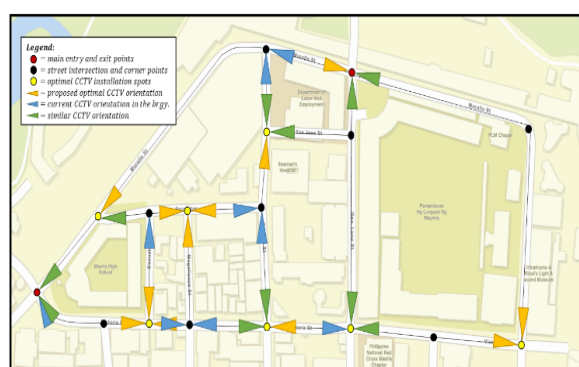

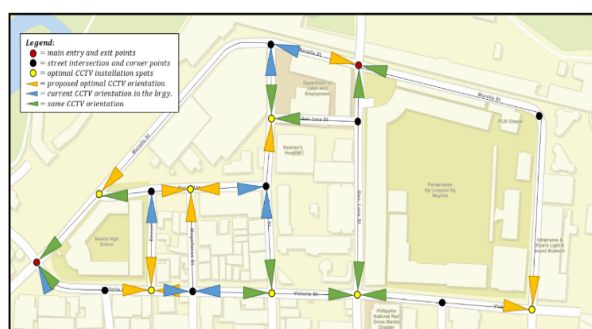Fig. 44. Current CCTV Orientations of the District vs. Result A obtained from the Study.

Fig. 45. Current CCTV Orientations of Barangay 657 vs. Result B of the Study.

Sure enough, the optimal solutions presented in the study graphically assure that every street across the district is monitored by CCTV cameras. However, the comparison and suggestions of the proposed model are under constraints that limit the validity of the study when applied in real-life scenarios. When applied to real problems, basic metrics such as street distances and CCTV camera specifications are to be considered. This will be taken up in our future study.

N. Quantity

At present, there are a total of twenty CCTV units installed in the CCTV system of the district that are placed at separate locations within the walls of Intramuros. Both optimal solutions A and B suggest the installation of twenty-three camera units in different strategic locations of the district to cover all the street sections divided by street crossings. While the number of surveillance units recommended by the study is greater in quantity, the constraints formulated by this study guarantee that every entry or exit point of each street in the community is sufficiently surveilled.

On the other hand, the operational surveillance system of the district does not include the monitoring of all the surrounding areas as shown by the absence of a CCTV unit assigned to observe the street sections represented by B, J, K, L, P, R, and W as shown in Fig. 45. Additionally, some CCTV units that exist in the barangay are oriented towards one another, which may not be optimal if the formulated goal is to cover all the streets with minimal cost. Furthermore, two CCTV cameras installed and directed in the same positions are counter-intuitive in a minimization problem.

Then again, the researchers adhere to the scope and limitations of the study and understand that there are other deciding factors that can be considered in camera placement planning. Other determination variables concerning the camera specifications or varied cost assignment of prioritization are recommended by the researchers to be explored by interested scholars.

O. Suggestions for Optimality

The researchers suggest that no two CCTV cameras in the system should have the same installation spot positioned at identical orientations specifically if there is only a limited number of available units. Also, the cameras that mirror themselves on monitoring the same street sections should be reconsidered especially for those placed at smaller street segments. This is to maximize the number of accessible surveillance cameras and provide monitoring of other sections of the barangay.

Some of the significant street sections in the barangay lack CCTV units to watch over them in the existing network. It is highly recommended to consider installing surveillance cameras in these areas, particularly the intersection of Sta. Lucia and Victoria which is represented by vertex 17. The long roads that are in this junction and the adjacent landmarks that exists should be given ample monitoring as well. However, the researchers understand that some areas are remotely located with respect to the Barangay Hall and that there are additional costs when considering the cables that will be used to link the CCTV system.

The similarities between the current CCTV placements of the barangay and the collected results of the study are an indication that some of the surveillance cameras are already

placed at their optimum location and orientation. Out of the twenty units in the existing network, the twelve parallels between candidate result B and the modeled CCTV system of the barangay are indicative that result B is more optimal. Moreover, the discussions in Phase I give more weight to placing the camera in vertex 15. In line with this, the researchers chose the optimized model of CCTV camera placement represented by candidate result B since lesser discrepancies mean lesser adjustment costs.

VI. SUMMARY OF FINDINGS

This study aimed to provide an optimization model for solving CCTV camera placement in District 5, Intramuros, Manila. Specifically, the main objective was to determine the best CCTV installation spots in the district and the optimal orientation of the CCTV cameras such that all the entry and exit points of the street sections in the district are optimally covered by minimum quantity of surveillance units. Moreover, it was also the goal of this study to suggest optimal changes to the current CCTV Monitoring System of the district.

The researchers used 2-dimensional graphs to model the target environment by representing the candidate optimal installation spots and street sections of the district as vertices and edges, respectively. The solution approach was divided into two phases namely, Phase I and Phase II. Phase I was utilized for the identification of the best installation spots for CCTV units as a set-covering problem and Phase II introduced the algorithm that was used to determine the optimal camera orientations. A binary integer programming model was formulated and solved using MS Excel Data Solver in Phase I, and consequently provided the data for the final stage (Phase II). The designed algorithm in Phase II created a directed graph of the modeled target environment where the directed edges were indicative of the optimal orientation of each CCTV unit.

Phase II generated two distinct optimal solutions. These are denoted by Result A and Result B. Both results were compared with the current CCTV system of the district. The discussions in Phase I as well as the comparison with the existing surveillance network in the area led the researchers to conclude that result B is the optimal solution relative to CCTV camera placement of the district.

Out of the seventeen candidates for the optimal CCTV-installation locations, nine distinct street intersections were identified as optimal. The first two are the intersections between Muralla and Gen. Luna, and Muralla and Victoria, which represent the main entry-exit points of the district. The other seven candidates include the junctions of the following street pairs: Recoletos & Muralla, San Jose & Cabildo, Recoletos & Magallanes, Victoria & Escuella, Victoria & Cabildo, Victoria & Gen. Luna, and Victoria & Sta. Lucia.

Overall, the optimal orientation of each CCTV unit is illustrated by the result B consisting of twenty-three surveillance cameras that are assigned to monitor the street sections of the barangay divided by road junctions. The main entry-exit points of the barangay should be installed with CCTV cameras pointing towards all their incident streets that are inside the premises of the district within the walls of Intramuros. Meanwhile, the other optimal installation

locations were assigned to have CCTV units directed towards their incident street sections that are not yet being monitored by cameras from other optimal installation spots. The special case of determining which of the two adjacent optimal locations (Victoria & Cabildo and Victoria & Gen. Luna) should monitor the street section of Victoria lies on the discussions made concerning each optimal installation spot and the comparison of the existing CCTV system in the district.

With regards to the current CCTV system of the district, recommendations on avoiding overlapping the camera units, such that they monitor the same street sections, were emphasized by the researchers. Surveillance on street junctions that were not being monitored by the district's surveillance network was proposed in the study. The optimal solution (Result B) for the CCTV camera placement was recommended for immediate implementation.

VII. CONCLUSIONS

The researchers conclude that having a comprehensive CCTV system in District 5 is not just an elective component of the community but instead a necessity, especially in these modern times. The findings of this study were indicative of how a systematic and well-planned surveillance network can greatly benefit the constituents of Intramuros, Manila. The chosen community consists of multiple educational institutions providing secondary education, tertiary education, and post-graduate degrees. Additionally, an executive department of the Philippine government and establishments showcasing significant fragments of the country's history also reside within the district. Numerous businesses providing different services to both the locals and visitors are situated in the vicinity. Being in a neighborhood that exists within the walled city of Intramuros, it is expected that tourists and visitors coming from different parts of the world will go across the regions included in the district. Crimes exist where there are people, and hence crime deterrent strategies such as surveillance networks are crucial element of a modernized community.

The researchers deduced that formulating the dilemma mathematically such as identifying the optimal spots for CCTV installation and the optimum installation cost within the specific place of interest as a set covering problem is an ideal approach. Additionally, the research recognized that it is feasible to design a unique algorithm suitable to the requirements of the formulated optimization problem utilizing collated results from an LP model. In line with this, CCTV camera placement can be possibly modeled in a two-stage methodology, which includes the proposal of an algorithm to process the results gathered in a set-covering problem.

Lastly, this study acknowledges the fact that a purely mathematical approach to the problem can possibly yield different optimal solutions. The final optimization model of CCTV camera placement being proposed in this study is a culmination of both the LP model derived from the present scenario and the pre-defined evaluations of the existing characteristics of the district.

VIII. RECOMMENDATIONS

In accordance with the findings and the conclusions made in this study, the following are recommended:

The authorities of District 5 should consider the result of proposed optimization model for solving CCTV camera placement in the community. It is highly suggested that surveillance units must be added to the junction of Sta. Lucia and Victoria Street at the corner of the district near the Light and Sound Museum. Moreover, the placement and orientations of other CCTV units that are not considered optimal are recommended to be adjusted at the moment the surveillance network will be modified or upgraded.

Additionally, the personnel that will be assigned to install the CCTV cameras along the streets of the district should consider the ideal elevation of the units such that no physical elements of the environment can hinder clear monitoring of the streets, and no unwanted vandalism on the utilities can possibly occur. Each surveillance camera is recommended to have ample coverage to prevent the units from being rusty and to prolong its operational lifespan.

On the other hand, the researchers advise the constituents and visitors of the district to refrain from performing vandalism on the public CCTV units monitoring the neighborhood. In addition, they must not be complacent just because they have surveillance cameras watching over streets. CCTV cameras are of extremely help in maintaining safety and security and can even provide recorded evidence against robbery incidents. It is one way of instigating fear in criminals and persuading them not to engage in unlawful acts as their anti-social behavior is recorded by the CCTV recording system.

It is highly recommended that the high-resolution CCTV cameras with special features for facial recognition and license plate recognition must be installed in the district. These CCTV cameras are capable of capturing license plate number of a moving and non-moving vehicles. They can provide high accuracy and reliable evidence against traffic offenders and carnappers.

Lastly, the researchers recommend the exploration of the effectiveness of the algorithm in other places of interest. It is also suggested that other decision factors such as camera specifications, maximum range, and the total coverage of the streets will be taken into consideration in the future study. Furthermore, the researchers also recommend the branch and bound method in determining optimal camera placement of the same area.

CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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