Proposal of a Coverage Model to Support the Surveillance and Security Management in the Asunción Botanical Garden and Zoo

Fabrizio N. Recalde-Rivas, Jorge L. Recalde-Ramírez and María M. López
Grupo de Investigación de Operaciones y Logística
Departamento de Ingeniería Industrial
Facultad de Ingeniería
Universidad Nacional de Asunción
San Lorenzo, Paraguay
frecalde@fiuna.edu.py, jrecalde@ing.una.py, mmlopez@ing.una.py

Abstract
In order to generate comprehensive strategies that address the activity of providing security to basic public goods, the State establish policies. For this reason, for public spaces, especially those administered by municipalities, it is relevant to have a good security and surveillance system which attends to the large flow of people (users). In the process of providing these services, it is crucial to optimize the available resources. Currently, the Municipality of Asunción manage the Asunción Botanical Garden and Zoo (JBZA). In the present work, we analyze the current situation of the park, with the aim of design a coverage mathematical model to support the security and surveillance system of recreational and sports areas. The proposal is based on the theory of fixed coverage, where the installation location of the servers is indicated, and the objective is to maximize the demand covered by the security posts to be installed in 28 zones of the JBZA. In addition, due to the limited availability of information, an approximation of the demand of the zones is made. We compare the results obtained with the current working model.

Keywords
Security, Coverage, Park, Location of facilities.

1. Introduction
For service provision problems, as is the case of security management and surveillance of public spaces managed by government entities, it is valid to apply an Operations Research (IO) tool. Based on the theory of location models, more specifically coverage models. Firstly, the current situation of the security and surveillance system must be surveyed, detailing the available resources such as human resources, material resources and economic resources. Subsequently, a mathematical model of deterministic coverage must be designed. (Ballou, 2004) In said model, its objective could be to maximize the coverage of the demand of the zones, employing security personnel strategically located in security posts. In the first place, the recreational and sports areas of the property would be zoned, and then the proposed model would be applied, efficiently assigning the available resources to each zone, in order to provide service to the demand of the zones. With the implementation of the proposal, it is estimated that social and economic benefits will be generated. For the first case, it would occur because the users would have the feeling of greater security in the property due to the visible organization of the personnel, increasing the level of control in the JBZA. And for the second case, due to the efficient administration of resources, it would be possible to optimize costs. Having as a result a coverage plan for the recreational and sports areas of the JBZA. In the first part, an introduction to the case study is made and then the applied methodology is exposed, which goes from the approach of the problem with the survey of data of the current situation to the development and analysis of the mathematical model with its result.

1.1 Objectives
1.1.1 General Objective
- Design a coverage plan for the security and surveillance system for the recreational and sports areas of the Asunción Botanical Garden and Zoo (JBZA).

1.1.2 Specific Objectives
- Describe the current situation of the surveillance and security management system in the JBZA

- Determine the relevant parameters related to the management of the surveillance and security system of recreational and sports areas.
- Design a deterministic location model, specifically a deterministic coverage mathematical model for the surveillance and security system.
- Solve the mathematical model with a computational language.
- Prepare a support coverage plan for the surveillance and security system, in accordance with the analysis of the results obtained with the programmed model.

2. Literature Review

The Literature review shows the research works that address the efficient management of security and surveillance, which were used as reference for this work. These works are mostly based on linear programming models.

In the article by Alfares & Alzahrani (2020), a workforce programming perspective is exposed that has two phases for security personnel at motor traffic gates. An entire programming model is formulated in order to allocate security guards to different shifts and thereby meet the staff requirements for each of the doors, this being the second phase. With the objective of minimizing the financial costs assigned for the total payment of the workforce, which are divided into categories: supervisors, who are security employees who carry out the task of supervising, and guards, who they do not supervise. In the design of the new model, scenarios with multiple locations, shifts, and types of employees are considered, in which security personnel are assigned to work groups. To maximize the degree of flexibility, it is proposed that each staff can be assigned to a task at different doors throughout different shifts. (Alfares & Alzahrani, 2020)

It is possible by means of a graph to represent the game of Spies. A single spy moves through the vertices, traveling at a certain speed s, while several guards move slowly, seeking to keep one of the spies between them at a distance d at all times of movement. In order to determine the minimum number of guards needed for this activity, Linear Programming is used as a way of analyzing the game. To then compare the similarities between integral strategies in trees and fractional and with this it is possible to develop a polynomial time programming algorithm and with this to be able to generate an optimal strategy for this type of graphs. Through the characteristic of duality that Linear Programming has, it also establishes a non-trivial limit for the fractional number of guards, thereby generating a lower limit for the number of guards in said graph. (Cohen et al., 2020)

The goal of the Art Gallery problem is to minimize the number of security guards needed in order to achieve optimal coverage of the Art Gallery area with that number of security guards. This work seeks to minimize the total consumption of electrical energy, taking into account that each point of the polygon will be illuminated. To solve the problem posed, two practical resolution methods were proposed, considering static luminaires. One of the methods used is based on the nonlinear programming method and the other method is based on a discrete approximation. (Ernestus et al., 2017)

This article exposes a multi-objective mixed-integer linear programming dynamic model, which seeks to optimize the allocation of helicopters and ships for search and rescue (SAR) work, in order to improve the performance of search and rescue missions. maritime. This model works with simulated incident scenarios to estimate demand and thus be able to designate a new location for vessels. It has three objectives that allow generating a balanced distribution of work among the different vessels and also reduce total costs. Set objectives, categorize them with a criterion of level of importance. There is a database with historical AEGEAN SEA incidents as a backup, and with it to be able to improve rescues and searches, in order to generate better action plans in decision making and thus help planners in the utilization scheme. of resources. (Karatas, 2020)

The work aims to minimize the damage inflicted on physical networks, by applying a Linear programming model and agent-based modeling. (Krohl et al., 2021)

Optimization formulations with mixed integer models are an interesting alternative when seeking to solve Strackelberg game problems, games that arise from a security application and investigation of the use of the branch and price method to solve the mixed integer optimization formulation. Production algorithms such as price and branch methods make it possible to build instances large enough to render inspiring games in the real world. (Lagos et al., 2017)

Murray's work aims to maximize the coverage of security sensors by using optimization-based techniques. (Murray et al., 2007)

3. Methods

3.1 Statement of the problem

The Botanical and Zoological Garden of Asunción was founded in 1919 by German scientists (Figure 1). Currently the property has 250 hectares, and is administered by the Municipality of Asunción (Pico and Ferreira, 2014), and is in Asunción, capital of Paraguay

For the scope of this work, the recreational and sports areas are taken, which comprise a semi-natural space of 116 hectares for public use.

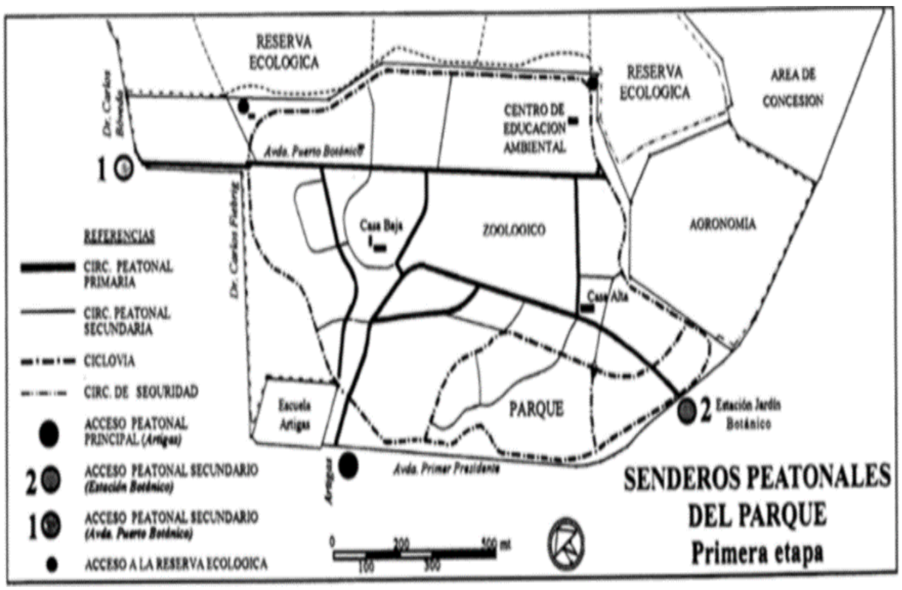

Figure 1. Map of the park's pedestrian paths

3.2 Data Sources

The collection and obtaining of data in the present work, it was carried out with:

- The bibliographic review of related works.
- The literature review that addresses the background and current situation of the JBZA.
- Interviews with officials from the security department and administrative department of the JBZA and the Municipality of Asunción.
- Information requests note to the Municipality of Asunción, the JBZA, and the government portal for access to public information of the Paraguayan government.

4. Data Collection

4.1 Problem statement

To address the coverage problem of the JBZA, more specifically its recreational and sports areas, it is proposed to use the model of the Maximum Coverage Location Problem, MCLP. The model seeks to locate servers and, in this process, optimize the values that are considered important (Bosques and Franco, 1995). In this research we need to locate security guards at points of demand, to patrol within the assigned area, considering that resources are finite and scarce. It is proposed to minimize the number of guards to be located. (Recalde et al., 2022)

4. 2 Zoning

The following criteria were used for the zoning of the JBZA recreation and sports areas:

- Areas that present a division or border, which acts as a border
- Sites defined by the administration, such as the rose garden, the Picnik area, the lake, etc.
- The characteristics of the area in relation to its flora.
- It was considered a delimiting factor of the existing areas, trails and constructions

After zoning, 28 delimited zones were obtained, which can be seen on the satellite map in Figure 2.

Figure 2. JBZA Zone Map - Recreational and Sports Areas

4.3 Description of the Zones

With the aforementioned criteria, the zones of the recreational and sports areas were delimited, the characteristics of each of them are set out below, emphasizing the distance between the plants and their size. (Recalde et al., 2022)
For the zoning, the description of the 28 zones was made. Here we describe 3 zones:

Zone 1: has trees that have a good separation between them, the range of vision of the JBZA users is good. There are tall trees of different species, as shown in Figure 3.

Figure 3. JBZA Zone 1

Zone 2: It is observed in Figure 4, zone 2 with the presence of tacuara trees, known scientifically by the name of Guadua Chacoensis, that are large trees that cover the vision of users and isolate them These trees are dense and are found on both sides of the path.

Figure 4. JBZA Zone 2

Zone 5: As shown in Figure 5, the area has very short grass, so there is visibility at a great distance. In addition, trees can be seen separated from each other.

Figure 5. JBZA Zone 5

4.4 JBZA Adjacency Matrix

An adjacency matrix has multiple uses, one of them is to determine equivalence relations in elements of a graph. These graphs can be represented through binary matrices (contain values 0 or 1).
For the assembly of the matrix, adjacent zones are areas that have more than one point in common. Therefore, those areas that have one or more sides in common are adjacent zones.
Figure 6 is a graphic representation with nodes, which represents the zones. The lines that join the nodes exhibit the interrelationships between them, which in this case it would be the shared perimeter between the zones.

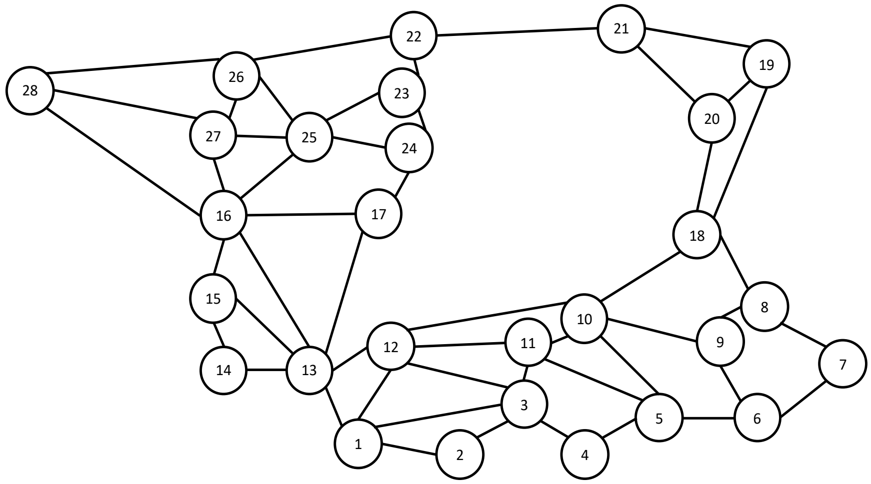

Figure 6. Graph of the 28 zones of the recreational and sports areas of the JBZA, according to the adjacency matrix

4.5 Approach of the demand in the zones

To calculate the demand covered, we approximate the parameter "potential demand" zone (h). Through an interview and tour in the areas with the Chief of Security Staff of the JBZA, an estimate of the load capacity of each area was made, using a scale of 1 to 10, and as a result we obtain the potential of demand h_z.

In the scale, the value 1 is given to the zone that has low demand (the minimum), and 10 is given to the zone that has high demand (the maximum). (Recalde et al., 2022)

Data were obtained setting the following considerations, that are more representative due to the large influx of people:

- Data from year 2019 (the years 2020 and 2021 are not representative due to the Coronavirus Pandemic).
- Spring, summer, and winter holidays.
- Weekends.
- Hours from 4:00 p.m. to 6:00 p.m.

The potential demand vector h_Z for the 28 zones is:

h_Z= {1:6, 2:4, 3:5, 4:4, 5:2, 6:6, 7:4, 8:5, 9:4, 10:8, 11:1, 12:2, 13:7, 14:9, 15:5, 16:5, 17:8, 18:9, 19:3, 20:1, 21:4, 22:4, 23:2, 24:10, 25:6, 26:4, 27:6, 28:4}

Using the MCLP model as a base, modifications are made to adapt it to the problem. Additional parameters are defined to calculate the demand F (its calculation is made difficult by the lack of data or historical records):

- h_z: potential demand in the zone $z \in Z$.
- $h_z^{máx}$: maximum potential demand in the zone $z \in Z$.
- N_z: number of people that can be found in the zone $z \in Z$.
- $N_z^{máx}$: maximum number of people that can be found in the zone z ∈ Z.

In Recalde et al. (2022), we present all the steps followed and calculations made to approximate the demand in the zones and to introduce it in the MCLP objective function showed in the equation (1) from the section 5.1 Programming.

5. Mathematical Model

To support the surveillance and security system of the JBZA, a location model is proposed (Maximal Covering Location Problem - MCLP). Location models aim to locate service centers, in such a way as to optimize values that are considered important when users use these services. In this case study, it is desired to cover the recreational and sports areas of the JBZA park by locating posts with security personnel that can circulate within a designated zone. In the Problem Statement section, the criteria for zoning the area were described and the need for coverage of the zones was defined.

5.1 Programming

Programming is considered, which takes the MCLP, as the selected base model and modifies it to represent the proposed problem.

Sets

- Zones: set of nodes that represent user demand points.

$$\boldsymbol{Z = 1, 2, \ldots, |Z|}$$

- Locations: set of nodes that represent candidate locations where to locate security personnel.

$$\boldsymbol{J = 1, 2, \ldots, |J|}$$

Parameters

- $\boldsymbol{p}$: security post number to be located.
- $\boldsymbol{a_{zj}} = \begin{cases} \boldsymbol{1,\ \textit{if the zone z can be covered by the post installed in j}} \\ \boldsymbol{0,\ \text{in the another case}} \end{cases}$

Variable:

- $\boldsymbol{F_z}$: zone demand $\boldsymbol{z} \in \boldsymbol{Z}$.

Decision Variables

- $\boldsymbol{x_z}$: binary variable that takes value 1 when the zone $\boldsymbol{z} \in \boldsymbol{Z}$ is covered, 0 when not.
- $\boldsymbol{y_j}$: binary variable that takes value 1 if a security personnel is located in $\boldsymbol{j} \in \boldsymbol{J}$, 0 when not.

Objective Function: Maximize the demand covered by security positions.

$$Max\ F = \frac{Q}{h|Z|}\sum_{z \in Z} h_z . x_z \quad (1)$$

Subject to:

With the constraint set:
(2) It is guaranteed that each area can be covered if at least one security post is installed to cover it.

$$x_z \leq \sum_{j \in J} a_{zj} . y_j \quad \forall z \in Z \ \ (2)$$

With (3) the number of facilities to locate is restricted.

$$\sum_{j \in J} y_j = p \ \ (3)$$

The nature of the decision variables is given by (4) y (5).

$$x_z \ \in \{0,1\} \quad \forall z \in Z \ \ (4)\,, \qquad y_j \ \in \{0,1\} \quad \forall j \in J \ \ (5)$$

5.2 Programming Results

A sensitivity analysis was carried out where the value $\boldsymbol{p}$ is varied, in the intervals of 1 and 28, these being the minimum and maximum values that it can take.
Table 1 shows the number of zones that are covered with the different variations of $\boldsymbol{p}$, the areas in which the security post will be installed, and the areas that are covered by the post.
It is observed that reaching $\boldsymbol{p}$ = 7, coverage of the 28 zones (100%) and the totality of the demand is achieved, a situation that is repeated in the interval since $\boldsymbol{p}$ it takes a value of 7 until it reaches a value of 28, visualizing that in all these states the conclusion is total coverage of the zones and the demand.

Table 1. Results – Coverage zones with variations of p

$\boldsymbol{p}$	**Covered Demand**	**Number of covered zones**	**Identification of covered zones**	**Zones where security personnel are installed**
1	150	7	1, 12, 13, 14, 15, 16, 17	13
2	250	12	1,12, 13, 14, 15, 16, 17, 23, 24, 25, 26, 27	13, 25

3	343	18	1, 3, 4, 5, 6, 10, 11, 12, 13, 14, 15, 16, 17, 23, 24, 25, 26, 27	5, 13, 25
4	421	22	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 23, 24, 25, 26, 27	5, 8 ,13, 25
5	464	26	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27	5, 8 ,13, 21, 25
6	479	27	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28	3, 9, 15, 20, 24, 26
7	493	28	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28	3, 7, 9,15, 20, 24, 26
≥8	493	28	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28	$j \in J' : J' \subseteq J$ $y_j = 1$

Figure 7 shows a representation of the behavior of the variation in covered demand, we observe the growth that the amount of demand covered is having as the number of security posts installed increases in the interval of $\mathbf{1 \leq p \leq 7}$. Reaching the top from $\mathbf{p = 7}$, where the amount of demand covered is total, and with $\mathbf{p > 7}$ the demand covered is constant. In other words, with $\mathbf{p = 7}$, the optimal and total coverage is obtained.

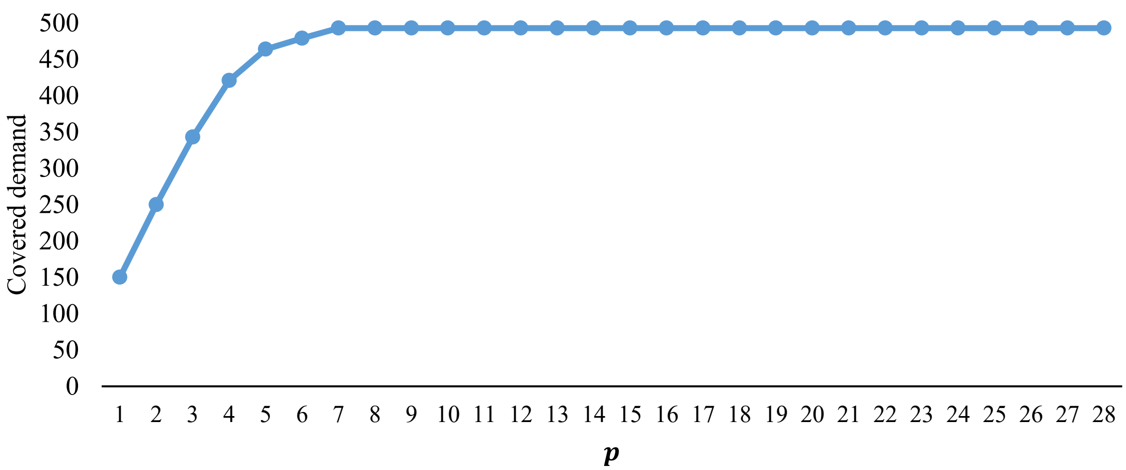

Figure 7. Dot plot - Number of zones covered in the JBZA with variations of $\boldsymbol{p}$

Considering the above results, we present the analysis, taking 7 as the number of posts to be located, exposing it configuration features.

Table 2 shows the areas where security personnel are installed, detailing the areas covered by each security personnel. The coverage of all areas occurs with $\mathbf{p = 7}$.

Table 2. Results with $p = 7$

Zones where the security post is installed	Covered zones	Number of covered zones
3	1, 2, 3, 4, 5, 11, 12	7
7	6, 7, 8	3
9	6, 8, 9, 10	4
15	13, 14, 15, 16	4
20	18, 19, 20, 21	4

24	17, 23, 24, 25	4
24	22, 25, 26, 27, 28	5

Figure 8 represents the optimal solution, by means of a graphical representation of results with $\boldsymbol{p} = \mathbf{7}$, visualizing where the security posts should be located and which areas can be covered with it, a panorama shown previously in Table 2.

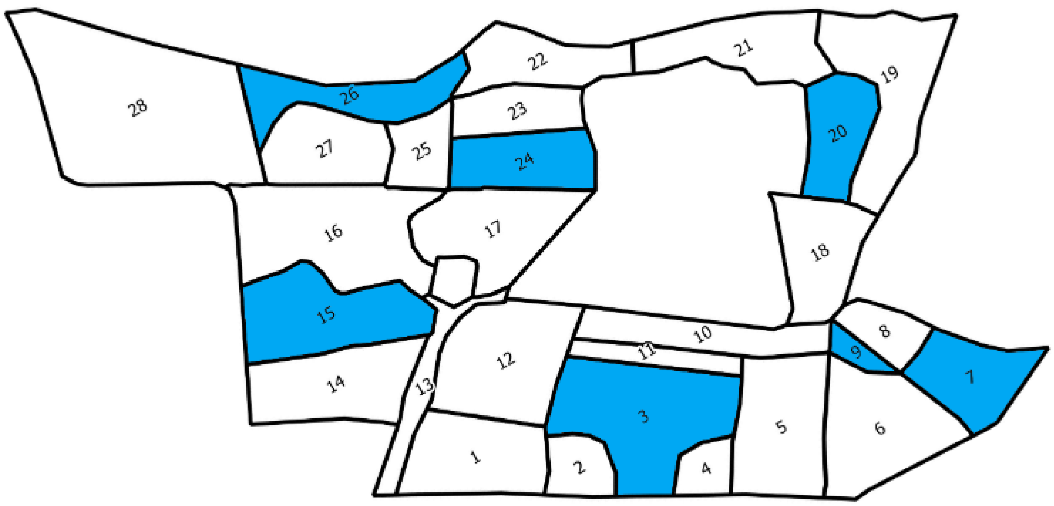

Figure 8. JBZA map with security posts located with $\boldsymbol{p} = \mathbf{7}$

Figure 9 shows the locations of the 7 security posts in a network of graphs that represent the JBZA zones, under the constraints of the MCLP model.

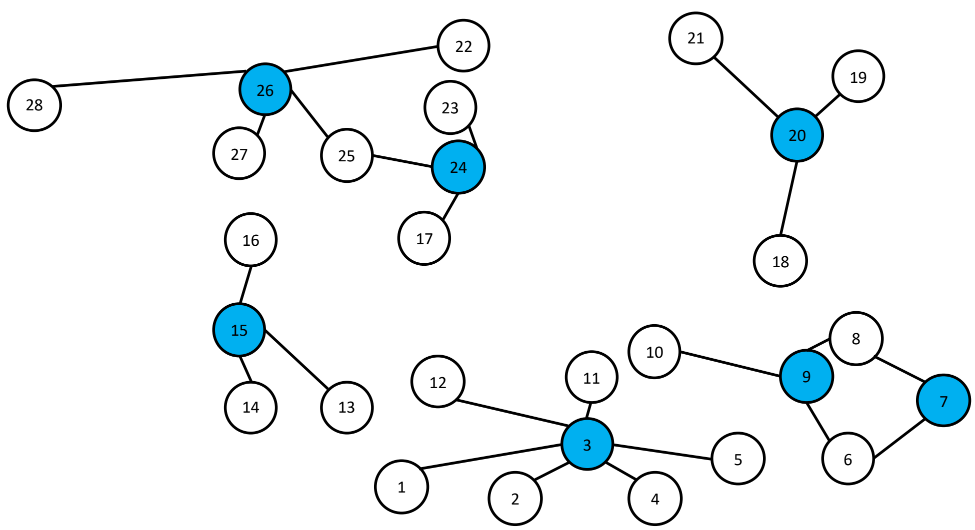

Figure 9. Network graphs of JBZA security posts located with $\boldsymbol{p}$=7

5.3 Current real scenario

With a survey made to the Municipality of Asunción and interviews to the staff, the current situation was described. The JBZA currently has 36 own security personnel dependents on the JBZA Security Department, who are divided into different shifts (morning, afternoon, and night).

The time slot contemplated for this work covers the morning shift and the afternoon shift, since the scope of the work is limited to entering the recreational and sports areas. In the morning and afternoon shift there are 7 security personnel, and 3 of them are intended for recreational and sports areas. Therefore, in the real scenario, 3 security personnel were considered.

6. Conclusion

With the proposed methodology, a deterministic coverage model was designed to support the security and surveillance system of the recreational and sports areas of the Asunción Botanical Garden and Zoo (JBZA). The model was programmed in Python computational language, and the solutions were obtained with the Gurobi optimization software (academic license).

With a series of considerations, some calculations were made to estimate the covered demand, and a zoning of the property was carried out. Having as an optimal result the installation of 7 security posts in 7 locations, and with this the coverage of 493 people (100% of the demand) is ensured, which is equivalent to providing coverage to 28 zones (100% of the zones).

According to the current situation and the results of the programming, it is suggested: Increase the security personnel, from 3 to 7 troops for the recreational and sports areas per shift (morning and evening).

References

Alfares, H. K. Alzahrani y A. S., "Optimum workforce scheduling for multiple security gates", INFOR: Information Systems and Operational Research, vol. 58, no. 3, pp. 438–455, 2020, https://doi.org/10.1080/03155986.2019.1629770

Ballou R., "Logística: Administración de la cadena de suministro". 5ta. ed. México: Pearson Educación, 2004.

Bosque J., Franco y S., Modelos de localizacion-asignacion y evaluación multicriterio para la localización de instalaciones no deseables, 1995, pp. 163.

Cohen, N., Mc Inerney, F., Nisse, N., & Pérennes,S.(2020). Study of a Combinatorial Game in Graphs Through Linear Programming. In Algorithmica (Vol. 82, Issue 2). Springer US. https://doi.org/10.1007/s00453-018-0503-9

Ernestus M., S. Friedrichs, M. Hemmer, J. Kokemüller, A. Kröller, M. Moeini, y C. Schmidt, "Algorithms for art gallery illumination", Journal of Global Optimization, vol. 68, no.1, pp. 23–45, 2017, https://doi.org/10.1007/s10898-016-0452-2

Hillier F., Lieberman y G., "Introducción a la Investigación de Operaciones", 9na. ed. México: McGraw-Hill, 2010.

Karatas M., "A dynamic multi-objective location-allocation model for search and rescue assets", European Journal of Operational Research, vol. 288, no. 2, pp. 620–633, 2020, https://doi.org/10.1016/j.ejor.2020.06.003

Kroshl W. M., Sarkani S., Mazzuchi y T. A., "Efficient Allocation of Resources for Defense of Spatially Distributed Networks Using Agent-Based Simulation", Risk Analysis, vol. 35, no. 9, pp. 1690–1705, 2015, https://doi.org/10.1111/risa.12325

Lagos F., Ordóñez F., Labbé y M., "A branch and price algorithm for a Stackelberg Security Game", Computers and Industrial Engineering, vol. 111, pp. 216–227, 2017, https://doi.org/10.1016/j.cie.2017.06.034

Murray A. T., Kim, Davis K. J. W., R. Machiraju, R., Parent y R., "Coverage optimization to support security monitoring", Computers, Environment and Urban Systems, vol. 31, no. 2, pp. 133–147, 2007, https://doi.org/10.1016/j.compenvurbsys.2006.06.002 (2006).

Pico O., Ferreira y M., "El Botánico, Nuestro jardín. Un siglo de Vida (1914-2014)". Asunción: Servilibro, 2014.

Recalde et al. Coverage plan for surveillance and civil security: case of application in recreational and sports areas of a municipal park. Manuscript submitted for publication (2022).

Biography

Fabrizio Recalde graduated from the Facultad de Ingeneira Universidad Nacional de Asunción (FIUNA) in Industrial Engineering in 2022. Participated and won first place in October 2014 at the CIENCAP science fair at Asunción Escalada School. Participated in Expo-Sciences International (ESI) Brussels Belgium 2015. Vice president 6th, class president 7th, 8th, 9th and 10th semester. Sub Secretary of university extension of the FIUNA Student Center (CEI) (2018-2019). Academic Manager of the Department of Industrial Engineering FIUNA (2019-2021). IEEE volunteer and member (2019-2022). Vice President of IEEE IAS UNA (2020-2021).

Jorge Recalde has a master's degree in Industrial Engineering, and a Doctoral Candidate in Engineering Sciences. Teaching experience: Assistant Professor of Operations Research, Professor of Logistics, Tutor of final degree projects. Professional experience: Planner in the pharmaceutical industry, Logistics Coordinator in the food industry. His lines of research and interest are Operational Research, particularly Optimization, Operations Management

Margarita Lopez has a master's degree in Industrial Engineering and is Doctoral Candidate in Engineering Sciences. Teaching experience: Assistant Professor of Operations Research, Professor of Production Planning and Control, Production Organization, Tutor of final degree projects. Professional experience: Production supervisor in the food industry. Research Lines: Operational Research, Optimization and Management of Production and Logistics Operations.

Acknowledgments

The authors thank to the Department of Industrial Engineering of the Faculty of Engineering - National University of Asunción for their support in this research.