OPTIMIZING POLICE VISIBILITY: AN ANALYTIC HIERARCHY PROCESS – INTEGER PROGRAMMING MODEL FOR PATROL BEAT ASSIGNMENT IN AN URBAN CITY IN THE PHILIPPINES

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ABSTRACT*: The strategic deployment of patrol police in key areas serves as a vital crime deterrent within the community. However, the challenge arises from the limited number of available police personnel, posing difficulties for administrators to effectively allocate resources in order to maximize visibility.*

This study aims to provide a method for prioritizing allocation of patrol beat personnel around an urban city in the Philippines. The proposed approach incorporates various preferences such as crime rate, population, traffic flow, the number of establishments found in the area and lighting, through an Analytic Hierarchy Process-based integer programming (AHP-IP) model. Results indicate that the AHP-IP model offers a more realistic approach to patrol police allocation compared to the current allocation strategy. Consequently, the findings suggest that the method outlined in this study could be instrumental for local police office in enhancing their service delivery through improved patrol personnel allocation within the community.

Keywords: Location-Allocation problem, Analytical Hierarchy Process (AHP), Integer Programming, Patrol Beat.

1. INTRODUCTION

In the fast-changing landscape of urban cities in the Philippines, effective law enforcement and public safety management are very important for the well-being of every citizen in the community. One critical aspect of maintaining a secure environment is the strategic allocation of patrol resources to address potential security threats promptly. In this context, the application of advanced decision-making approaches becomes crucial.

The allocation of patrol police is a critical aspect of law enforcement strategy, and various models and methodologies have been employed to optimize the deployment of police resources. Mitchell [1] determined the advantage of patrol districting through minimization of expected weighted response distance and increase in time of available for preventive patrols. The study presented practical static optimization models for the efficient geographic distribution of police patrol manpower. The models were then used to determine the optimal selection of beat patrol using one-year incident data from Anaheim, California in which the two primary functions of patrol, answering calls for service and deterrence, were simultaneously satisfied.

Zhang and Brown [2] reviewed the characteristics of the police patrol district design problem from the perspective of past and current work. In their paper, patrol districting plans generated using a parameterized redistricting procedure were evaluated using an agent-based simulation model. This police patrol districting approach was then used for the Charlottesville Police Department and the solution generated showed improvement on both average response time and variation of the workload through the complete simulation study. Simulation results further showed that patrol performance can be improved compared with the current districting solution.

In addition, Curtin, et al. [3] presented a new method for determining efficient spatial distributions of police patrol areas. The study employed a traditional maximal covering model formulation and an innovative backup covering formulation which provided alternative optimal solutions to police decision makers. Consequently, the study was able to develop a method for integrating geographic information systems (GIS) with linear programming optimization to generate and display alternative optimal solutions, and to formulate an innovative backup coverage model that is appropriate for police patrol area design. The proposed method was then applied to police geography of Dallas, Texas and showed that optimal arrangement can substantially improve police efficiency.

Some allocation models on police patrol are typically formulated using integer linear programming models. Namoco, et. al [4] solved police assignment problem of the different police stations within the central business district in Cagayan de Oro City using integer programming. They determined the number of policemen to assign and where to position them during their shift to attain maximum protection and police visibility. Given the limited number of patrol police in the country, another paper by Namoco, et al [5] looked into prioritizing the patrol beat locations around Cagayan de Oro City, Philippines through the use of the analytic hierarchy process (AHP).

The AHP, as introduced by Saaty [6] in 1980, considers a set of evaluation criteria and a set of alternative options among which a best decision is arrived. It involves breaking down the problem into a standardized set of components, and organizing them according to a hierarchy in order to incorporate significant quantities of information and present a more comprehensive portrait of the problem. The pairing of the elements at each level of the hierarchy is done by assigning a weight to each element as shown in Table 1.

Table 1. The AHP rating scales as used in this study.

Level of Importance	Description	Explanation
1	Equally important	Two activities equally contribute to achieve the goal.
3	Moderately more important	Experience and judgment moderately favor one activity over the other.
5	Strongly more important	Experience and judgment strongly favor one activity over the other.
7	Extremely more important	Practice has shown that an activity is very highly favored over the other.
9	Absolutely important	One activity is definitely more probably than the other.
2, 4, 6, 8	Intermediate values	When a compromise is required.
½, 1/3, …, 1/9	Reciprocal values	If the activity A has value *x*, when in comparison to activity B, activity B must be given (1/*x*).

Through the use of the AHP, [5] found that crime rate is considered the topmost basis for determining locations of patrol beat for both day and night shifts. Distance of the beat location to police station is also found to be of utmost importance when deciding where to locate patrol beats. Results from [5] are shown in Tables 2 and 3. Clearly, preference rankings are affected by

Table 2. Preference weights for the day shift.

Criteria for Day Shift	Weight
Crime Rate	0.37
Distance to the Police Station	0.06
Traffic	0.23
Number of Open Establishments	0.23
Population	0.16
Road Length/Accessibility	0.04

Table 3. Preference weights for the night shift.

Criteria for Night Shift	Crime Rate
Crime Rate	0.34
Distance to the Police Station	0.07
Number of Open Establishments	0.18
Population	0.13
Road Length/Accessibility	0.06
Well-lit Areas	0.20

Using these criteria, Namoco, et al [7] provided an analysis on how the varying preferences on these criteria would affect the ranking among beats in a given location. Table 4 summarizes the weights obtained for 4 beat areas when the preference on the criterion crime changes through different values.

By integrating the weights obtained using the AHP results, this study focused on providing a holistic decision-making process that considers both qualitative priorities and quantitative allocation for a more effective and adaptive resource allocation strategies in law enforcement.

This paper is organized as follows. Section 1 presents background information on the present study. Methodology is discussed in Section 2 while results and discussion are presented in Section 3. A brief conclusion is given in Section 4.

2. Methodology

As earlier discussed, this study involves incorporating the relative importance of criteria into the objective function in order to determine the optimal allocation of patrol beat personnel around the city using a weighted AHP-based integer programming model. The general patrol beat allocation problem (GAP) model is described as follows:

$$\text{maximize } Z = \sum_{i=1}^{n} D_i x_i$$

subject to

$$x_i \geq D_i, \ \forall i$$
$$\sum_{i=1}^{n} x_i \leq \text{ Total available personnel}$$
$$x_i \geq 0, \forall i$$

where x_i is the number of patrol beat personnel assigned to location *i;*

D_i is the demand for patrol beat personnel at location i (based on factors such as crime rates, population density, etc.) and

n is the total number of locations.

The objective of this problem is to maximize the total number of patrol beat personnel assigned per location i while constraint (1) ensures that the required number of personnel assigned for each location is satisfied while constraint (2) requires that the total number of personnel assigned is equal to the total available personnel.

To present a more realistic allocation model for the patrol beat personnel, we incorporate weights in the IP model based on various preferences as obtained using the AHP-model presented in [5] and the variations considered in [7]. By incorporating weights on the LP model, the patrol beat allocation model is described as follows:

$$\text{maximize } Z = \sum_{i}^{n} c_i x_i$$

subject to

$$x_i \geq m_i \text{ }, \forall i$$
$$x_i \leq M_i, \forall i$$
$$\sum_{i=1}^{n} x_i \leq \text{ Total available personnel}$$
$$x_i \geq 0, \forall i$$

where m_i and M_i are the minimum and maximum number of patrol beat

personnel to allocate for each location *I*, respectively; and

c_i is the preference weight associated with patrol beat location *i*.

In this model, our goal is to maximize visibility by strategically allocating patrol beat personnel to locations based on the preference weights.

3. RESULTS AND DISCUSSION

To better illustrate our proposed model, we determine the patrol beat personnel allocation by computing the weight preferences of the Table 4 patrol beat locations as presented in [7] using the criteria used in the AHP model presented in [5]. These values are shown in Table 5.

Using these weight preferences, we solve the patrol beat allocation problem when the total available patrol beat personnel is set at 11, $m_i \geq 1$ and the values of M_i is at most 2, 3, 4,5,6 or 7. The resulting allocations are shown in Table 5.

Table 4. Weight preferences of the 4 patrol beat locations.

TRIAL	Weight Preferences for Patrol beat locations			
	1	2	3	4
1	0.3	0.24	0.27	0.19
2	0.1	0.5	0.22	0.18
3	0.28	0.1	0.12	0.5
4	0.15	0.25	0.5	0.1
5	0.2	0.05	0.6	0.15
6	0.5	0.3	0.1	0.1
7	0.4	0.4	0.05	0.15

.Table 5. Patrol beat personnel allocation for different maximum values M_i.

TRIAL	Patrol Beat Personnel Allocation					
	At $M_i \leq 2$	At $M_i \leq 3$	At $M_i \leq 4$	At $M_i \leq 5$	At $M_i \leq 6$	At $M_i \leq 7$
1	(2,2,2,2)	(3,3,3,2)	(4,2,4,1)	(5,1,4,1)	(6,1,3,1)	(7,1,2,1)
2	(2,2,2,2)	(2,3,3,3)	(1,4,4,2)	(1,5,4,1)	(1,6,3,1)	(1,7,2,1)
3	(2,2,2,2)	(3,2,3,3)	(4,1,2,4)	(4,1,1,5)	(3,1,1,6)	(2,1,1,7)
4	(2,2,2,2)	(3,3,3,2)	(2,4,4,1)	(1,4,5,1)	(1,3, 6,1)	(1,2,7,1)
5	(2,2,2,2)	(3,2,3,3)	(4,1,4,2)	(4,1,5,1)	(3,1,6,1)	(2,1,7,1)
6	(2,2,2,2)	(3,3,3,2)	(4,4,2,1)	(5,4,1,1)	(6,3,1,1)	(7,2,1,1)
7	(2,2,2,2)	(3,3,2,3)	(4,4,1,2)	(5,4,1,1)	(6,3,1,1)	(7,2,1,1)

Results shown in Table 5 indicate a noticeable difference in allocations for each patrol beat location, corresponding to the weights assigned to these locations. Furthermore, the results highlight that, with an increase in the maximum allowable personnel, the variations in allocation become more pronounced.

4 CONCLUSION

The study highlighted the impact of varying preferences on the criteria employed to determine personnel allocation for patrol beats. As a result, the weights associated with each patrol beat location play a crucial role in influencing the fluctuations in the allocated personnel numbers across the different locations. This result is very significant as it directly translates to enhancing police visibility in locations where it is most essential.

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