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An Integer Programming Approach for Patrol Police Allocation in an Urban City in the Philippines

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Abstract

Objectives: Philippine National Police (PNP) directed all PNP units to deploy policemen to perform beat patrolling duties for maximum police visibility as well as to intensify law enforcement operations, anti-criminality campaign and public safety services. Beats or beat areas are the areas where policemen are assigned to patrol. In conducting patrols, the officers intermingle and work with the general populace. Due to the limited number of available policemen to be assigned in the beats, this paper aims to solve a Patrol Police Allocation Problem (PPAP) which consists of allocating policemen to beat areas to ensure optimum police visibility in the Central Business District (CBD) of Cagayan de Oro City, Philippines. **Methods**: In this study, an integer programming model for the PPAP is developed and solved, while considering various characteristics of beat areas and the number of available of patrol police to be assigned. **Findings:** Results of the study show that the proposed model provides better police visibility than the current police allocation around the CBD of the city. **Application:** Results of this study will provide insights on how patrol police can be optimally allocated in various beat patrol areas.

Keywords: Integer Programming, Patrol Police, Police Assignment Problem

1. Introduction

To most citizens, the uniformed police officer represents the government, and is the most visible representative of governmental power seen on a daily basis. The police officer is looked to as a problem solver and often asked to be a social mediator between conflicting citizens, in essence the referee between good and evil. The police officer is expected to serve with a sense of justice, showing equal dedication and respect to all members of the community.

The major functions of a police department include the following: protect life and property; enforce the laws; prevent crime; preserve the peace; arrest violators; and serve the public. Crime control, one of the primary duties of law enforcement, is carried out through the services of patrol officers and criminal investigators. Patrol is considered the backbone of police activities in the preservation of peace and order[1]. In police terminology, a beat is the territory which a police officer patrols. Police officers have the duty to go around a populated area either by foot or in motor vehicles. Police go around within their respective beats to look for and apprehend criminals or to respond to citizens under threat or those who needs assistance.

In Cagayan de Oro City, there are ten (10) police stations. These are Police Station 1 (Divisoria), PS 2 (Cogon), PS 3 (Agora), PS 4 (Carmen), PS 5 (Macabalan), PS 6 (Puerto), PS 7 (Bulua), PS 8 (Lumbia), PS 9 (Macasandig) and PS 10 (Cugman). Each of these police stations has an Operations Department (OD) which takes charge of the whole assignment system of the beat patrols under their area of responsibility.

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Integer Programming (IP) models find various applications in solving real-world problems. Examples of application of IPs include capital budgeting, warehouse location and scheduling[2]. Scheduling problems arise in all walks of life, be it in hospitals, academe or security agencies. Various solution methods have been proposed to solve scheduling problems[3].

The traffic police routine patrol vehicle assignment problem on an interurban road network was considered in[4] using integer programming. Results of the study show that, using their proposed method, police coverage were more widely spread over the network as compared to existing practice[5] also used integer programming to determine spatially efficient allocations of law enforcement resources under varying scenarios.

In order to provide a better assignment of policeman or beat patrols within the Central Business District of Cagayan de Oro, this study uses integer programming in order to maximize police visibility within their respective areas of responsibility in the Central Business District (CBD) of Cagayan de Oro City, Philippines.

This paper is divided as follows. Section 1 gives an introduction of the problem considered in this paper. Section 2 provides terminologies, concepts and the methods used in this study. Results and discussions are given in section 3. A brief conclusion is provided in section 4.

2. Preliminaries

The policeman assignment model proposed in this study uses integer programming and is aimed at maximizing the protection on the beat/beats these policemen are assigned to. Police shifts are divided into two, namely, day and night shift. Since crime rates in the day shift differ from the night shift, the critical values of the beats also vary depending on the shift. In the Philippines, since not all areas are well-lit, night shifts are considered more prone to crimes than day shifts. Since this study only focuses on the CBD of the city, all data used in this study are obtained from the four police stations (1, 2, 3 and 9).To obtain maximum protection, existing beats are first evaluated. Critical values, denoted by c, are then assigned to the identified beats to indicate how critical these beats are. A survey among the different police stations in the city was conducted in order to determine these critical values.

The first step in their assignment process is classifying the beat areas. The OD considers a certain area/street as a beat area if it satisfies at least one of the following conditions: 1. Possibility of a crime in an area; 2. If it is an area of convergence; 3. If the area is a waiting area/sidewalk; 4. If the area is crowded (near schools/public establishments) and 5. If the area is dim or deserted. After the beat areas have been determined, beat patrols are then assigned depending on the number of policeman available in their police station. The number of beat areas and beat patrols differ from one station to another. Currently, police stations in Cagayan de Oro assign equal number of beat patrols according to the available number of policemen in their station.

The critical values assigned for day and night shifts are determined by the head of the Operations Department of every Police Station involved in this study. Criteria for assigning critical values of beat areas include 1. The number of establishments within the beat area; 2. The road length (if the beat is composed of roads or streets); 3. The traffic; 4. The crime rate; and 5. The lighting (for night shifts) of the beats. Establishments refer to academic institutions and business infrastructures located around the beat. Road length refers to how extensive some of the beats are since most of the beats classified by the police stations are roads or streets. Traffic refers to how busy the street around beat is. May be it is with regards to the vehicles or the people. Crime rate refers to how often a certain crime (considers only theft, robbery and physical injury) occurs in the beat area. Lastly, lighting refers to the lighting conditions around the beat area during night time.

Tables 1 and 2 show the criteria used to assign critical values among beats during day time and night time. Beats assigned with critical value 1 is considered to be the least critical among all the other beats under the scope of a certain police station. Beats with critical value equal to 2 has more establishments around it and the traffic sometimes gets busy. A critical value of 3 means the beat area is often busy and populated. These areas usually have medium length of streets which means that policemen assigned in these beats have to patrol in wider areas. Areas with critical value of are considered to be alarming due to the number of crime incidences occurring in these areas. Lastly, the maximum critical value that can be assigned in the classified beats is 5. This implies these beat areas are the most critical among all the other beats in the area of responsibility of a certain police station. Numerous establishments are located around these beats causing the people to converge in these areas. Populated areas are commonly crime prone during day time because this is where the criminals find greater opportunity to do crimes such as theft and pick pockets. For night time, an additional criterion, which is the lighting condition, is used in evaluating critical values of beats. This is due to the fact that during night time, some areas are not well-lit or do not even having lamp post at all. This is sometimes the reason why these areas are prone to crime incidence. At night time, some places are considered safer since business establishments are already closed around these areas. However, areas in which bars and restaurants operate until late at night are assigned with higher critical values.

Using these critical values, beat areas are then evaluated and assigned critical values according to their respective characteristics.

3. Results and Discussions

In the Philippines, all police stations have two work shifts: the day and night shift. Each shift has 12 hours of duty. The two shifts differ greatly. During daytime, some places become very crowded, hence require for more police visibility. On the other hand, night time may mean higher risk due to the lack of proper lighting in different areas in the city.

To provide a feasible and desirable result for our police assignment model (PAM), we consider the following basic constraints. We let x_{ij} be the number of police patrols to assign to each beat area, for each index set $i \in I$ and each shift $j = 1,2$, corresponding to day and shift, respectively.

A maximum of one (1) policeman must be assigned in beats with very low critical values which are 1. This means that for each beat area j=1, 2, $x_{kj} \leq 1$, where k∈K, the set of all beats with critical value equal to 1. In this case, a maximum of one (1) policeman is sufficient enough to patrol in these areas.

A policeman can be assigned to two adjacent beats with the lowest critical value. Hence, for each beat area j=1,2, $x_{kj} + x_{(k+1)j} \leq 1$. Adjacent beats with the lowest critical value are considered less critical compared to other beats. Hence, we assign no more than one (1) policeman to patrol these beats.

For beat areas with low critical value which is 2, there must be one (1) policeman assigned. That is, for each j=1,2, $x_{lj} = 1$, where $l \in L$, the set of all beats with critical value equal to 2.

Table 1. Criteria for assigning critical values during day time

Critical Value	Criteria			
	Open Surrounding Establishments	**Road Length**	**Flow of Traffic**	**Crime Rate**
"1" (Very Low)	Very Few	Short	Smooth	Very Low
"2" (Low)	Few	Short	Normal	Low
"3" (Average)	Several	Medium	Slightly Busy	Average
"4" (High)	Several	Medium	Busy	High
"5" (Extreme)	Numerous	Long	Very Busy	Very High

Table 2. Criteria for assigning critical values during night time

Critical Value	Criteria				
	Open Surrounding Establishments	**Road Length**	**Flow of Traffic**	**Crime Rate**	**Lighting Condition**
"1" (Very Low)	Very Few	Short	Smooth	Very Low	Excellent
"2" (Low)	Few	Short	Normal	Low	Good
"3" (Average)	Several	Medium	Slightly Busy	Average	Good
"4" (High)	Several	Medium	Busy	High	Bad
"5" (Extreme)	Numerous	Long	Very Busy	Very High	Poor

The number of policemen assigned in the beats with a critical value of 3 must be at least 1 but not more 2. Hence, for each j=1,2, $1 \leq x_{mj} \leq 2$, where $m \in M$, the set of all beats with a critical value of 3.

Beats with a critical value of 4 must be assigned two (2) policemen, hence, for each j=1,2, $x_{oj} = 2, o \in O$, the set of all beats with critical value of 4. Police visibility is more needed in areas with higher critical values to provide better security to the community.

The number of policemen assigned in the beats with the highest risk value must be at least 2 but not more than three (3). Hence, for each j=1,2, $2 \leq x_{pj} \leq 3$, where $p \in P$ is the set of all beats with critical value 5.

For the adjacent beats with the highest critical value, there must be at least four (4) policemen assigned. That is, for each j=1,2, $x_{qj} + x_{(q+1)j} \geq 4$, where $h \in H$, is the set of all beats with critical values of 4 and 5. This means that in cases when crimes occur unexpectedly in one of these adjacent beats with high critical value, some of the policemen on the adjacent beat can respond and provide protection to the other beat.

In cases when a beat area is adjacent to a barangay hall, the number of beat patrols assigned to this area is then fixed at one (1) since these barangays already have their own barangay police. Hence, for each=1,2, $x_{rj} = 1$, where $r \in R$ is the set of all barangays that are adjacent to a beat.

At most one (1) policeman must be assigned to beats that are adjacent to a police outpost. That is, for each j=1,2, $x_{sj} \leq 1$, where $s \in S$ is the set of all outposts under the Area Of Responsibility (AOR) of a police station that are adjacent to other beats.

Distant outposts and barangay halls under the AOR of a police station must be assigned with at least two (2) policemen. That is, for each j=1, 2, , where $t \in T$ is the set of all distant barangays and outposts under the scope of a police station.

Furthermore, we consider each of the following cases in the formulation of our patrol police allocation problem.

Case 1. If the total number of policemen in the day and night shifts is the same as the existing allocation.

$$\sum_{i=1}^{n} x_{i1} = d and \sum_{i=1}^{n} x_{i2} = n,$$

Where d is the total number of policemen assigned during day shift and n is the total number of policemen assigned during night shift.

Case 2. If there must be equal number of policemen on duty for the day and night shift.

$$\sum_{i=1}^{n} x_{ij} = \frac{t}{2},$$

Where t is the total number of policemen assigned in the classified beats in the day and night shift.

Case 3. If for each day, the total number of policeman assigned for the two shifts is equal to t.

$$\sum_{j=1}^{2}\sum_{i=1}^{n} x_{ij} = t$$

In summary, the Police Allocation Problem (PAP) model for the three cases considered in this study can be formulated as follows:

Case 1.

Maximize Z= $\sum_{j=1}^{2}\sum_{i=1}^{n} c_{ij}x_{ij}$

Subject t

(1) $\sum_{i=1}^{n} x_{i1} = d \sum_{i=1}^{n} x_{i2} = n$

For each j=1,2:

(2) $x_{kj} \leq 1$

(3) $x_{kj} + x_{(k+1)j} \leq 1$

(4) $x_{lj} = 1$

(5) $1 \leq x_{mj} \leq 2$

(6) $x_{oj} = 2$

(7) $2 \leq x_{pj} \leq 3$

(8) $x_{qj} + x_{(q+1)j} \geq 4$

(9) $x_{rj} = 1$

(10) $x_{sj} \leq 1$

(11) $x_{tj} = 2$

(12) $x_{ij} \geq 0.$

For Cases 2 and 3, the corresponding PAP models are similar to above except that constraint (1) is replaced by $\sum_{i=1}^{n} x_{ij} = \frac{t}{2}$ or $\sum_{j=1}^{2}\sum_{i=1}^{n} x_{ij} = t.$

By solving the IP formulation, we obtain the following proposed police allocation for each identified beat, as shown in Tables 3-6.

It can be seen from these tables that protection, as measured by the presence of police patrols in the area have significantly increased in the proposed allocation as compared to the existing police patrol allocation in all three cases considered. It may be observed that the proposed assignment for PS 3 provide a slight decrease in coverage as compared to the current. This could be attributed to the reduction of the assigned number of policemen in Beat Area 1 which has 5 policemen assigned in the current assignment. Consequently, in the proposed assignment, more beat areas are assigned with more than 1 policeman who would in turn ensure greater visibility.

Table 3. Current and proposed police assignment for Police Station 9

	Current		Proposed					
			Case 1		Case 2		Case 3	
	Day	Night	Day	Night	Day	Night	Day	Night
Beat 1 (XU, Lourdes BED)	2	1	1	0	1	1	1	1
Beat 2 (Corpus Christi)	1	0	1	0	1	1	1	0
Beat 3 (Macasandig Elem. School)	2	0	1	0	1	1	1	0
Beat 4 (St. Mary's School)	3	0	1	0	0	0	0	0
Beat 5 (21st Street Nazareth)	2	0	1	0	1	0	1	0
Beat 6 (1st Street Nazareth-FICCO)	1	0	1	0	1	0	1	0
Beat 7(Buena Oro South View Homes-Woodland Heights Aroville subdivision to Melicia homes)	1	1	2	2	2	2	2	2
Beat 8 (Tomas Saco 15th-26th Fern hill M Chavez st./ Tibasak)	1	0	1	0	1	0	1	0
Beat 9 (Tomas Saco 8th/16th Street Nazareth)	1	0	1	1	1	1	1	1
Beat 10 (Tomas Saco 6th/21st Street Nazareth)	3	0	1	1	1	1	1	1
Beat 11(15th Street/Mercury Drugstore)	2	0	1	0	0	0	0	0
Beat 12 (8th Street, CDONHS, Petron, Super Motors)	2	0	1	0	0	0	0	0
Beat 13 (Police Outpost Tomas Saco)	0	2	1	1	1	1	1	1
Beat 14 (Outpost Brgy. Nazareth- CDONHS)	0	1	1	1	1	1	1	1
Beat 15 (12th/29th Street Nazareth/St. Mary's School)	0	1	1	1	1	1	1	1
Beat 16 (Aluba Outpost and Lourdes BED)	0	1	2	2	2	2	2	2
Beat 17(Melicia Outpost)	0	1	2	2	2	2	2	2
Total number of policemen per shift	21	8	20	11	17	14	17	12
Overall Total	29		31		31		29	
Z	47		55		55		53	

Table 4. Current and proposed police assignment for Police Station 2

BEATS		Current		Proposed					
				Case 1		Case 2		Case 3	
		Day	Night	Day	Night	Day	Night	Day	Night
Sector 1	**B1** C.M. Recto Avenue (between Corrales & Osmeña Streets)	3	2	0	1	0	1	0	1
	B2 J.R. Borja Extension (between Limketkai Road & Osmeña Streets)			0	1	0	1	0	1
	B3 Limketkai Drive			0	1	0	1	0	1
Sector 2	**B4** J.R. Borja Extension	4	2	1	2	1	2	1	2
	B5 Bolonsiri Road			1	2	1	2	1	2
	B6 Hayes Street (from Osmeña going east)			1	1	1	1	1	1
Sector 3	**B7** Claro M. Recto Avenue (between Osmeña and Corrales Streets)	3	2	1	1	1	1	1	1
	B8 Corrales (C.M. Recto & DomingoStreet)			1	2	1	2	1	2
	B9 Capt. Vicente Street (between Yacapin & C.M. Recto Streets)			0	1	0	1	0	1
	B10 Jose Calo Agudo Street			0	0	0	0	0	0
	B11 Gen. A. Luna Street			0	1	0	1	0	1
	B12 J. Rivera Street			0	0	0	0	0	0
	B13 J. Ebarle Street			0	0	0	0	0	0
	B14 Ramon Chavez Street			0	0	0	0	0	0
	B15 Lt. Guillermo Street			0	1	0	1	0	1
	B16 Osmeña (between Yacapin & C.M. Recto Streets)			1	1	1	1	1	1
	B17 Justo Ramonal Street			2	2	2	2	2	2
Sector 4	**B18** Yacapin Street	13	3	2	2	2	2	2	2
	B19 Corrales Street (between Dominggo &Fernandez Streets)			1	2	1	2	1	2
	B20 Dominggo Street (between Corrales & OsmeñaStreets)			0	0	0	0	0	0
	B21 Fernandez Street (between Corrales &22nd Street)			1	1	1	1	1	1
	B22 Hayes Street (between Corrales & OsmeñaStreets)			2	2	2	2	2	2
	B23 J.R. Borja Street (between Corrales & OsmeñaStreets)			2	2	2	2	2	2
	B24 Mortola Street			1	1	1	1	1	1
	B25 Lt. Guillermo Street			1	1	1	1	1	1
	B26 Capt. Vicente (between Hayes & Yacapin)			2	1	2	1	2	1
	B27 Osmeña St. (between Hayes & Yacapin)			2	2	2	2	2	2
	Total number of policemen per shift	23	9	22	31	22	31	22	31
	Overall Total	32		53		53		53	
	Z	134		189		189		189	

Table 5. Current and proposed police assignment for Police Station 1

BEATS	Current		Proposed					
			Case 1		Case 2		Case 3	
	Day	Night	Day	Night	Day	Night	Day	Night
Beat 1 (Fernandez-Tiano-GaerlanStreets)	1	0	2	1	2	1	2	1
Beat 2 (Capistrano Streets)	1	0	1	2	0	2	0	2
Beat 3 (Barangay 9 & 10)	1	0	1	1	1	1	1	1
Beat 4(Chavez Street)	1	0	1	1	1	1	1	1
Beat 5 (Capistrano-Abellanosa Streets)	1	0	1	0	0	0	0	0
Beat 6 (Rizal Street)	1	0	1	1	1	1	1	1
Beat 7 (Yacapin-Tiano Streets)	1	0	1	1	1	1	1	1
Beat 8 (Velez-Montalban Streets)	1	0	1	0	0	0	0	0
Beat 9 (Abejuela Street)	1	0	1	0	0	0	0	0
Beat 10 (Corrales Outpost)	2	2	1	1	1	1	1	1
Beat 11 (City Hall Outpost)	2	2	1	1	1	1	1	1
Beat 12 (KioskoKagawasan)	0	1	1	0	0	0	0	0
Beat 13 (Velez-Luna Streets)	1	0	1	1	1	1	1	1
Total number of policemenevery shift	14	5	14	10	9	10	9	10
Total	19		24		19		19	
Z	38		55		50		50	

Table 6. Current and proposed police assignment for Police Station 3

BEATS	Current		Proposed					
			Case 1		Case 2		Case 3	
	Day	Night	Day	Night	Day	Night	Day	Night
Beat 1 (Market City & Integrated Bus Terminal)	5	3	3	3	3	3	3	3
Beat 2 (Metrobank Outpost-Cm Recto Highway including MUST Majesty Valenzuela Road)	2	2	2	2	2	1	2	2
Beat 3(Metrobank Outpost-Lapasan Overpass)	2	2	2	2	2	2	2	2
Beat 4 (Capistrano-Abellanosa Streets)	2	2	2	1	1	2	2	2
Beat 5 (Gaisano Mall Outpost- CU Corrales)	1	1	2	2	2	2	2	2
Beat 6 (BarangayLapasan and ECCS, Alagar Outpost)	1	1	2	1	2	2	1	1
Beat 7 (Gusa Outpost- Bigaan Creek, Eastbound Terminal to Gusa CUMC highway)	2	2	2	2	2	2	2	2
Total number of policemen every shift	15	13	15	13	14	14	14	14
Total	28		28		28		28	
Z	100		96		96		96	

4. Conclusions

In this study, a patrol police assignment has been proposed for the different police stations around the commercial business district of Cagayan de Oro City. Results showed that the proposed police assignments of police stations 1, 2 and 9 may provide increased protection than the current police assignment.

To provide better protection in the beat areas, it might be interesting to consider the case when exact positions of policemen within the beat areas are identified in such a way that whenever a post becomes vacant or needs assistance, the police in the adjacent beat can respond.

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