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On Optimal Allocation of Crime Preventing Patrol Team Using Dynamic Programming

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***ABSTRACT**: It is quite consensual that the police patrolling can be regarded as one of the best well-known practices for implementing public-safety preventive policies towards the combat of an assortment of urban crimes. Deploying adequate police patrol to hotspots areas based on available patrol units is even huge challenge. In time past, Nigerian police employed heuristic approaches to deploy crime preventive police patrol teams to the hotspots. These approaches are not necessary expected to yield optimal solutions to the problem of effectively allocating police patrol efforts across various hotspots. In this work, we present how dynamic programming can be used to bring about optimal solutions to the police patrol allocation problem. Data were collected from the Nigerian Police Command Headquarter, Benin City on crime statistics across eight precincts. These data were analyzed using the dynamic programming to determine the optimal solutions to the effective deployment of crime preventive police patrol force across the eight precincts.*

***KEY WORDS:** Optimal Allocation, Dynamic Programming, Police patrol, Hotspots*

I. INTRODUCTION

Decision making involves several decisions that need to be taken at different time. The mathematical techniques to optimize such a sequence of interrelated decisions over a period of time are called dynamic programming. It uses the idea of recursion to solve a complex problem, broken into a series of interrelated (sequential) decision also called (sub problems) where the outcome of a decision at one stage affects the decisions at each of the following stages.

Over the last three decades, policing has gone through a period of significant change and innovation in Nigeria. In a relatively short historical time frame, the police have reconsidered their fundamental mission, the nature of core strategies of policing, and the character of their relationships with the communities they serve. These changes and innovations grew out of concern that policing tactics did not produce significant impact on crime and disorder. There is now growing consensus that the police can control crime when they are focused on identifiable risks, such as crime hot spots, and when they use a range of tactics to address these ongoing problems (Tongo, 2010; UN, 2002; Olson and Wright, 1975). In Nigeria, these police innovations have been implemented by uniformed patrol officers rather than criminal investigators. In most police department, the ‘fruit’ of an investigation is the arrest and subsequent conviction of a criminal offender. Indeed, the work of criminal investigators in apprehending serious offenders can be incredibly creative, involve dogged persistence and include acts of heroism. We believe that the fruit of their labor can be the investigative knowledge and actions into crime-control strategies.

The problems of Nigerian Police in exercising its duties are both logistic and moral, over the years. In logistic terms, the force maintained by the federal government has not had enough equipment. The quantity of weapons, arms and ammunition available in most mobile squadron units in the country are hardly enough. There are some instances where the force cannot stand the counter firepower of armed bandit.Indeed, it appears that what is in Nigeria today is tantamount to a serious crime problem; hence, the main objective of this work is to give an insight into how optimal allocation of available number of police patrol units can effectively combat or intercept crime in some major street in Benin city, Nigeria. With the above aim in mind, analysis will be carried out on data collected, using the developed mathematical expression for the overall objective of the problem from the dynamic programming model developed.

II STRUCTURE OF THE NIGERIAN POLICE FORCE

Nigeria currently has centralized police force- Nigeria Police Force (NPF), established in 1930. This was sequel to the dissolution of Local Police Force in 1966. The 1979 and 1999 constitutions explicitly prohibited the establishment of police forces other than the Nigeria Police Force. Section 214 (1) stipulates:

"There shall be a Police Force for Nigeria, which shall be known as the Nigeria Police Force, and subject to the provisions of this section no other police force shall be established for the Federation or any part thereof."

The force is organized into 37 commands and the force headquarters. Each of the thirty- six states and the Federal Capital Territory is served by a command of the force. The force headquarter is the office of the Inspector General of Police. The task of the force is carried out through six departments. (1) Administration and Finance (2) Operations (3) Works and Logistics (4) General investigation and Intelligence (5) Training (6) Research and planning Each of the Departments is under the leadership of an Assistant Inspector – General of police. The 37 state police commands are further organized into 8 zonal commands. The Zonal commands are under the command of Assistance Inspector – General, while commissioners of police are in charge of state commands. The entire force is under the command and six Assistant Force Headquarters.

The Colonial Police Forces in Nigeria performed a variety of functions including:
Investigating and detecting crime, escorting residents and other officials, prosecuting offenders; guarding goals and prisoners at work outside the precincts of the prisons, serving summons and executing warrants; patrolling, aiding revenue and customs officials, guarding and escorting goods, and suppressing slave raiding. The colonial police were "general utility force". The functions of the Nigeria police are more clearly stated in section 4 of the police Act and Decree No 23 of 1979:

"The police shall be employed for the prevention and detention of crime, apprehension of offenders, the preservation of law and order, the protection of life and property, and due enforcement of all laws and regulations with which they are directly charge and perform such Military duties within or without Nigeria as may be required of them by, or under the Authority of this or any other Acts."

The police in the country also have statutory powers of investigation crime, apprehend offenders, interrogate suspects, prosecute suspects, grant bail to suspects pending completion of investigation or prior to court arrangement, to serve summons, to regulate or disperse unlawful processions and assemblies. The police are also empowered to search and seize properties suspected to be stolen or associated with crime, and to take record for purposes of identification, the measurements, photographs and fingerprints impressions of all persons.

III. MODEL FORMULATION

In this section, model formulation is carried out. In formulating the model certain notations are used. The definition of these notations is given as follows;

$f_j(s_j, x_j)$=total weighted probability of a patrol initiated intercept of a random crime in precinct j

x_j =the number of police patrol units to be allocated to the precincts.

x_j^*= the value of x_j that maximizes $f_j(s_j, x_j)$

$f_j(s_j)$ = the corresponding value of $f_j(s_j, x_j)$

$w(\theta)$ = the subjective weights assigned to each crime types which reflect the relative importance of intercepting
different types of crime.

$f(\theta, j)$= Relative frequency of each crime type θ in each police precinct j.

$N(j)$= Number of patrol units allocated to precinct j.

$P[\theta, j, N(j)]$= Probability of intercepting crime type θ in precinct j when $N(j)$ units are patrolling the region. It is a function of three parameters: total distance covered by the patrol units in each street, the speed of the patrol car and crime type observable time.

M = Total number of police patrol units available for allocation.

Our interest is to maximize the weighted probability of a police patrol initiated intercept of a random crime, subject to the number of patrol units available.

The model for the problem is:

$$max \sum_{j=1}^{n} P_j(x_j) = max \sum_{j=1}^{k} w(\theta_i) \cdot \sum_{j=1}^{n} f(\theta, j) \cdot P[\theta, j, N(j)] \qquad ... 3.1$$

where $P_j(x_j)$ is the measure of performance (i.e. weighted probability of a police initiated intercept of a random crime) from allocating x_j police patrol units to precinct j.

Subject to:

$$\sum_{j=1}^{n} x_j = M \qquad ... 3.2$$

Where $x_j > 0$ (decision variable) and

$$f_j(s_j, x_j) = P_j(x_j) + f_j(s_j - s_j) \qquad ... 3.3$$

Where the maximum is taken over $x_{j+1}, ..., x_n$, such that

$$\sum_{j}^{n} x_j = s_j, \quad j = 1,2, ..., n \qquad ... 3.4$$

But,

$$f^*(s_j) = max\, f_j(s_j, x_j) \qquad ... 3.5$$

Therefore;

$$f_j(s_j, x_j) = P_j(x_j) + f_{j+1}^*(s_j - x_j) \qquad ... 3.6$$

With f_{n+1}^* defined to be zero.

Hence, the recursive equation for the functions $f_1^*, f_2^*, ..., f_n^*$ in this problem is

$$f_j(s_j, x_j) = \max[P_j(x_j) + f_{j+1}^*(s_j - x_j)] \qquad ... 3.7$$

$$j = 1,2, ..., n - 1.$$

For the last stage $(j = n)$.

$$f_n^*(s_n) = \max P_n(x_n) \qquad ... 3.8$$

Where, $x_n = 0, 1, 2, ..., s_n$.

IV. DATA PRESENTATION

In this Section we present the data collected from Edo State Police Command Head Quarter, Benin City. The data collected are the crime statistics on Kidnapping, Armed Robbery, Burglary and Stealing, Murder, Arson and, OBT- Obtained money under force pretence across the eight precinct under study from 2010 – 2012, the total distance covered by the police patrol across each precincts, the observable duration of each crime, the speed of the patrol vehicle in each precincts, and the probability of intercepting the various crime type across precincts. The precincts in this context are hotspots described by the following major roads in Benin City. They are Uselu, Sapele, Ekenwa, Siloko, Akpakpava, Mission, Sakpoba and Okhoro roads. The reason for selecting these major roads is that crime is not spread evenly across urban landscapes; rather, it clumps in some relatively small places (that usually generate more than half of all criminal events) and almost completely absent in some others. Hotspots refer to those high crime density areas (target or precincts) that deserved to be better controlled by routine patrol surveillance or other more specific police actions. For the purpose of this work, data collection is restricted to crimes committed along the above mentioned roads. The table below shows various crime statistics from the eight precincts as recorded by the police command.

Table 4.1: Three years crime frequency in various precincts.
Source: Nigerian Police Command Headquarters, Benin City.

Crime Precincts	Murder	Kidnapping	Robbery	Arson	Burglary/ Stealing	OBT	Total
Uselu Rd.	6	3	10	2	16	24	61
Sapele Rd.	8	5	18	-	6	28	65
Ekenwa Rd.	2	3	32	1	8	12	58
Siloko Rd.	4	1	17	2	3	23	50
Akpakpava Rd	-	-	28	-	12	33	73
Mission Rd	3	-	36	-	26	17	82
Sakpoba Rd	1	-	12	1	7	15	36
Okhoro Rd.	5	2	16	3	17	21	64
Total	29	14	169	9	95	173	489

In analyzing the data in Table 4.1,"subjective weights" w were associated with the seven crime type. This is eminent because some crimes gravity is more than others and may require more attention by the patrol units. In this work, we take the weights of each crime equivalent to its rank.

Table 4.2: The crimes weighted Probabilities.

Crime	Weight (w)	Weighted Probability $w(\theta_i)$
Murder	6	0.2857
Kidnapping	5	0.2381
Robbery	4	0.1905
Arson	3	0.1429
Stealing	2	0.0952
OBT	1	0.0476

In Table 4.2, the weighted probability column is obtained by taking the relative frequency of the weight of each crime.
The relative frequencies of the various crimes with respect to the various precincts are given in the table below.

Table 4.3: Relative frequencies of crime θ per precinct f

Crime Precincts	Murder	Kidnapping	Robbery	Arson	Burglary/ Stealing	OBT
Uselu Rd.	0.2069	0.2143	0.0592	0.2222	0.1684	0.1387
Sapele Rd.	0.2759	0.3571	0.1065	0	0.0632	0.1618
Ekenwa Rd.	0.069	0.2143	0.1893	0.1111	0.0842	0.0694
Siloko Rd.	0.1379	0.0714	0.1006	0.2222	0.0316	0.1329
Akpakpava Rd	0	0	0.1657	0	0.1263	0.1908
Mission Rd	0.1034	0	0.2130	0	0.2737	0.0983
Sakpoba Rd	0.3450	0	0.0710	0.1111	0.0737	0.0867
Okhoro Rd.	0.1724	0.1429	0.0947	0.3333	0.1789	0.1214

The probability of intercepting a crime type in each street is directly proportional to the crime type observable time and the proportion of police patrol units available for the road and inversely proportional to the total surveillance distance covered during patrol.

$$P[\theta, j, N(j)] \propto \frac{crime\ type\ observable\ time}{total\ patrol\ distance\ covered} \times \frac{number\ of\ police\ patrol\ units\ allocated\ to\ street\ \hbar}{total\ number\ of\ police\ patrol\ available\ .} \qquad \ldots 4.1$$

$$P[\theta, j, N(j)] = k\left(\frac{crime\ type\ observable\ time}{total\ patrol\ distance\ covered}\right) \times \frac{number\ of\ police\ patrol\ units\ allocated\ to\ street\ \hbar}{total\ number\ of\ police\ patrol\ available\ .} \qquad \ldots 4.2$$

where k is a constant taken as the speed of patrol car.

Data collected from the police command Headquarter Benin City shows that 30 patrol units were available in the command and that the average patrol car speed is 32km/hr across the eight precincts. The table below shows the total patrol distance covered in the various precincts.

Table 4.4: Total distance covered in each precinct

Precincts	**Uselu Rd**	**Sapele Rd.**	**Ekenwa Rd.**	**Siloko Rd.**	**Akpakpava Rd.**	**Mission Rd.**	**Sakpoba Rd.**	**Okhoro Rd.**
Distance	38Km	46Km	48Km	46Km	36Km	39Km	45Km	49Km

The observable time for each crime type is the time taken for a successful crime type by the criminal. Data collected for successful crime type is given below.

Table 4.5: Average Crime type observable time per hour

Crime Precincts	**Murder**	**Kidnapping**	**Robbery**	**Arson**	**Burglary/ Stealing**	**OBT**
Uselu Rd.	0.5	0.5833	0.5667	0.4167	0.4333	0.3
Sapele Rd.	0.5333	0.65	0.6667	0.5333	0.4167	0.3833
Ekenwa Rd.	0.7167	0.45	0.7167	0.4667	0.5167	0.45
Siloko Rd.	0.4667	0.6	0.6333	0.7	0.65	0.5333
Akpakpava Rd	0	0	0.6	0	0.6333	0.2667
Mission Rd	0.6667	0	0.8333	0	0.3667	0.3167
Sakpoba Rd	0.8667	0	1.0833	0.8167	0.4833	0.3167
Okhoro Rd.	0.4667	0.3	0.65	0.4667	0.4167	0.2833

V. APPLICATION OF THE MODEL

The model stated in section 4.1 is used in this section on the data collected and presented in section 4.0. The LHS of equation 3.1 is used to calculate the weighted probability of a police patrol initiated intercept of crimes in each of the eight major roads in Benin City as given above.The table below gives the weighted police patrol initiated probability of intercepting the aforementioned crime type in each of the indicated precincts when a certain number of police patrol units are allocated to them. For instance, allocating seven patrol units to Akpakpava road yield 0.0072 weighted police initiated probability of intercepting crimes in that particular precinct. For the purpose of illustration, we assume that ten police patrol units are available for allocation to the eight precincts.

Table 5.1: Weighted police patrol initiated probability of intercepting crimes.

Precincts / Patrol Units	1 Uselu Rd	2 Sapele Rd	3 Ekenwa Rd	4 Siloko Rd	5 Akpakpava Rd.	6 Mission Rd	7 Sakpoba Rd	8 Okhoro Rd.
0	0	0	0	0	0	0	0	0
1	0.0035	0.0039	0.0024	0.0023	0.0012	0.0025	0.0014	0.0024
2	0.0069	0.0075	0.0047	0.0045	0.0025	0.0049	0.0027	0.0046
3	0.0087	0.0108	0.0067	0.0065	0.0036	0.0071	0.0039	0.0066
4	0.0126	0.0138	0.0086	0.0083	0.0047	0.0090	0.0050	0.0084
5	0.0151	0.0166	0.0103	0.0010	0.0056	0.0108	0.0060	0.0101
6	0.0175	0.0191	0.0119	0.0015	0.0064	0.0125	0.0069	0.0117
7	0.0196	0.0215	0.0134	0.0129	0.0072	0.0140	0.0078	0.0131
8	0.0216	0.0237	0.0148	0.0142	0.0080	0.0155	0.0086	0.0145
9	0.0235	0.0257	0.0160	0.0155	0.0087	0.0168	0.0093	0.0157
10	0.0252	0.0276	0.0172	0.0167	0.0093	0.0181	0.0100	0.0169

The dynamic programming model formulated in section 3.0 is used on the data in tables presented in section 4.0 to provide an optimal solution to allocate the ten police patrol units across the precincts. Here the stages correspond to roads and state s is the number of patrol unit available for allocation. Since there are eight precincts, the dynamic programme solution would involve eight stages. Thus the general recurrence equation will become:

$$f_j^*(s_j, x_j) = \max[P_j(x_j) + f_{j+1}^*(s_j - x_j)] \qquad \ldots 5.1$$
$$0 \le x_j \le s_j, \qquad j = 1,2,\ldots,8.$$

Using backward induction, we start by optimizing the last stage. The computations in each stage are shown below:

The recursive equation for Stage 8 is $f_8(s_8, x_8) = Max\, P_8(x_8)$

Table 5.2: Computations for Stage 8 $(j = 8)$

s_8	0	1	2	3	4	5	6	7	8	9	10
$f_j^*(s_8)$	0	0.0024	0.0046	0.0066	0.0084	0.0101	0.0117	0.0131	0.0145	0.0157	0.0169
f_8^*	0	1	2	3	4	5	6	7	8	9	10

The recursive equation for Stage 7 is $f_7(s_7, x_7) = P_7(x_7) + f_8^*(s_7 - x_7)$

Table 5.3: Computations for Stage 7 $(j = 7)$

s_7 \ x_7	0	1	2	3	4	5	6	7	8	9	10	$f_7^*(x_7)$	x_7^*
0	0											0	0
1	0.0024	0.0014										0.0024	0
2	0.0046	0.0038	0.0027									0.0046	0
3	0.0066	0.006	0.0051	0.0039								0.0066	0
4	0.0084	0.008	0.0073	0.0063	0.005							0.0084	0
5	0.0101	0.0098	0.0093	0.0085	0.0074	0.006						0.0101	0
6	0.0117	0.0115	0.0111	0.0105	0.0096	0.0084	0.0069					0.0117	0
7	0.0131	0.0131	0.0128	0.0123	0.0116	0.0106	0.0093	0.0078				0.0131	1
8	0.0145	0.0145	0.0144	0.014	0.0134	0.0126	0.0115	0.0078	0.0086			0.0145	1
9	0.0157	0.0159	0.0158	0.0156	0.0151	0.0144	0.0135	0.0124	0.011	0.0093		0.0159	1
10	0.0169	0.0171	0.0172	0.017	0.0167	0.0161	0.0153	0.0144	0.0132	0.0117	0.01	0.0172	2

The recursive equation for Stage 6 is $f_6(s_6, x_6) = P_6(x_6) + f_7^*\ (s_6 - x_6)$

Table 5.3 Computations for Stage 6 ($j = 6$)

s_6 \ x_6	0	1	2	3	4	5	6	7	8	9	10	$f_6^*(x_6)$	x_6^*
0	0											0	0
1	0.0024	0.0025										0.0025	1
2	0.0046	0.0049	0.0049									0.0049	1 or 2
3	0.0066	0.0071	0.0073	0.0071								0.0073	2
4	0.0084	0.0091	0.0095	0.0095	0.009							0.0095	2 or 3
5	0.0101	0.0109	0.0115	0.0117	0.0114	0.0108						0.0117	3
6	0.0117	0.0126	0.0133	0.0137	0.0136	0.0132	0.0125					0.0137	3
7	0.0131	0.0142	0.015	0.0155	0.0156	0.0154	0.0149	0.014				0.0156	4
8	0.0145	0.0156	0.0166	0.0172	0.0174	0.0174	0.0171	0.014	0.0155			0.0174	4 or 5
9	0.0159	0.017	0.018	0.0188	0.0191	0.0192	0.0191	0.0186	0.0179	0.0168		0.0192	5
10	0.0172	0.0184	0.0194	0.0202	0.0207	0.0209	0.0209	0.0206	0.0201	0.0192	0.0181	0.0209	6

The recursive equation for Stage 5 is $f_5(s_5,\ x_5) = P_5(x_5) + f_6^*(s_5 - x_5)$

Table 5.4 : Computations for Stage 6 ($j = 5$)

s_5 \ x_5	0	1	2	3	4	5	6	7	8	9	10	$f_5^*(x_5)$	x_5^*
0	0											0	0
1	0.0025	0.0012										0.0025	0
2	0.0049	0.0037	0.0025									0.0049	0
3	0.0073	0.0061	0.005	0.0036								0.0073	0
4	0.0095	0.0085	0.0074	0.0061	0.0047							0.0095	0
5	0.0117	0.0107	0.0098	0.0085	0.0072	0.0056						0.0117	0
6	0.0137	0.0129	0.012	0.0109	0.0096	0.0081	0.0064					0.0137	0
7	0.0156	0.0149	0.0142	0.0131	0.012	0.0105	0.0089	0.0072				0.0156	0
8	0.0174	0.0168	0.0162	0.0153	0.0142	0.0129	0.0113	0.0072	0.008			0.0174	0
9	0.0192	0.0186	0.0181	0.0173	0.0164	0.0151	0.0137	0.0121	0.0105	0.0087		0.0192	0
10	0.0209	0.0204	0.0199	0.0192	0.0184	0.0173	0.0159	0.0145	0.0129	0.0112	0.0093	0.0209	0

The recursive equation for Stage 4 is $f_4(s_4, x_4) = P_4(x_4) + f_5^*(s_4 - x_4)$

Table 5.5: Computations for Stage 4 ($j = 4$)

s_4 \ x_4	0	1	2	3	4	5	6	7	8	9	10	$f_4^*(x_4)$	x_4^*
0	0	0										0	0
1	0.0025	0.0023										0.0025	0
2	0.0049	0.0048	0.0045									0.0049	0
3	0.0073	0.0072	0.007	0.0065								0.0073	0
4	0.0095	0.0096	0.0094	0.0090	0.0083							0.0096	1
5	0.0117	0.0118	0.0118	0.0114	0.0108	0.001						0.0118	1 or 2
6	0.0137	0.014	0.014	0.0138	0.0132	0.0035	0.0015					0.0140	1 or 2
7	0.0156	0.016	0.0162	0.016	0.0156	0.0059	0.004	0.0129				0.0162	2
8	0.0174	0.0179	0.0182	0.0182	0.0178	0.0083	0.0064	0.0129	0.0142			0.0182	2 or 3
9	0.0192	0.0197	0.0201	0.0202	0.02	0.0105	0.0088	0.0178	0.0167	0.0155		0.0202	3
10	0.0209	0.0215	0.0219	0.0221	0.022	0.0127	0.011	0.0202	0.0191	0.018	0.0167	0.0221	3

The recursive equation for this stage is $f_3(s_3, x_3) = P_3(x_3) + f_4^*(s_3 - x_3)$

Table 5.6 : Computations for Stage 3 ($j = 3$)

s_3 \ x_3	0	1	2	3	4	5	6	7	8	9	10	$f_3^*(x_3)$	x_3^*
0	0											0	0
1	0.0025	0.0024										0.0025	0
2	0.0049	0.0049	0.0047									0.0049	0 or 1
3	0.0073	0.0073	0.0072	0.0067								0.0073	1
4	0.0096	0.0097	0.0096	0.0092	0.0086							0.0097	1
5	0.0118	0.012	0.012	0.0116	0.0111	0.0103						0.012	1 or 2
6	0.014	0.0142	0.0143	0.014	0.0135	0.0128	0.0119					0.0143	2
7	0.0162	0.0164	0.0165	0.0163	0.0159	0.0152	0.0144	0.0134				0.0165	2
8	0.0182	0.0186	0.0187	0.0185	0.0182	0.0176	0.0168	0.0134	0.0148			0.0187	2
9	0.0202	0.0206	0.0209	0.0207	0.0204	0.0199	0.0192	0.0183	0.0173	0.016		0.0209	2
10	0.0221	0.0226	0.0229	0.0229	0.0226	0.0221	0.0215	0.0207	0.0197	0.0185	0.0172	0.0229	2 0r 3

The recursive equation for Stage 2 is $f_2(s_2, x_2) = P_2(x_2) + f_3^*(s_2 - x_2)$

Table 5.7: Computations for Stage 2 ($j = 2$)

s_2 \ x_2	0	1	2	3	4	5	6	7	8	9	10	$f_2^*(x_2)$	x_2^*
0	0											0	0
1	0.0025	0.0039										0.0039	1
2	0.0049	0.0064	0.0075									0.0075	2
3	0.0073	0.0088	0.01	0.0108								0.0108	3
4	0.0097	0.0112	0.0124	0.0133	0.0138							0.0138	4
5	0.012	0.0136	0.0148	0.0157	0.0163	0.0166						0.0166	5
6	0.0143	0.0159	0.0172	0.0181	0.0187	0.0191	0.0191					0.0191	5 or 6
7	0.0165	0.0182	0.0195	0.0205	0.0211	0.0215	0.0216	0.0215				0.0216	6
8	0.0187	0.0204	0.0218	0.0228	0.0235	0.0239	0.024	0.0215	0.0237			0.024	6
9	0.0209	0.0226	0.024	0.0251	0.0258	0.0263	0.0264	0.0264	0.0262	0.0257		0.0264	7
10	0.0229	0.0248	0.0262	0.0273	0.0281	0.0286	0.0288	0.0288	0.0286	0.0282	0.0276	0.0288	6 or 7

The recursive equation for Stage 1 is $f_1(s_1, x_1) = P_1(x_1) + f_2^*(s_1 - x_1)$

Table 5.8: Computations for Stage 1 ($j = 1$)

x_1	0	1	2	3	4	5	6	7	8	9	10	$f_1^*(x_1)$	x_1^*
s_1 10	0.0288	0.0299	0.0309	0.0301	0.0317	0.0317	0.0313	0.0304	0.0291	0.0274	0.0252	0.0317	4 or 5

Table 5.1 – 5.8 gives the relationship between current and previous stages using (5.1) in determining the optimal solution to the police patrol allocation problem designed.

VI. DISCUSSION OF RESULTS

The analysis above yields two optimal solutions that result in a cumulative weighted probability of a police patrol initiated intercept. In table 5.8, the maximum return, i.e. the optimal probability of intercepting crime is 0.0317, correspond to the decision of allocating 4 or 5 patrol units to Uselu road, which leaves, $S = 10 - 4 = 6$ patrol units or $S = 10 - 5 = 5$ patrol units for other stages. Consequently, from Table 5.7, it suggest that the maximum of 6 or 7 patrol units will yield optimal return, but we have 6 or 5 patrol units remaining. This is within the bound. Thus, 6 or 5 patrol units respectively is allocated to Sapele road leaving $S = 6 - 6 = 0$ patrol units or $S = 5 - 5 = 0$ patrol units for the rest roads i.e. no patrol units for the other roads. These decisions are shown in the table below.

Table 5.9: Optimal Decision 1

Precincts	No. of Police Patrol Units	Weighted Probability
Uselu Road	4	0.0126
Sapele Road	6	0.0191
Ekenwa Road	0	0
Siloko Road	0	0
Akpakpava Road	0	0
Mission Road	0	0
Sakpoba Road	0	0
Okhoro Road	0	0
Total	**10**	0.0317

Table 5.10: Optimal Decision 2

Precincts	No. of Police Patrol Units	Weighted Probability
Uselu Road	5	0.0151
Sapele Road	5	0.0166
Ekenwa Road	0	0
Siloko Road	0	0
Akpakpava Road	0	0
Mission Road	0	0
Sakpoba Road	0	0
Okhoro Road	0	0
Total	**10**	0.0317

The consequence of the analysis is a cumulative weighted probability of 0.0317 for a police patrol initiated intercept of crime. This is the best any heuristic method can give because from Table 5.1, no other 10 possible police units allocation that can yield a cumulative probability of intercepting crimes greater than 0.0317.

VII. CONCLUSIONS

Police patrolling is an important instrument for implementing preventive strategies towards the combat of criminal activities in urban centers, mainly those involving violence aspects (such as Kidnapping, Armed Robbery, Burglary and Stealing, Murder, Arson and, OBT- Obtained money under force pretence etc.). An underlying hypothesis of such preventive work is that, by knowing where the occurrences of crime are currently happening and the reasons associated with such, it is possible to make a more optimized distribution of the police resources available to control or intercept the overall crime rate. In view of this, we attempted to develop a dynamic programming model for optimal allocation of police patrol units to intercept these crimes. For illustration, crime data were collected from police command headquarters, Benin City, for eight precincts and the model was used to allocate ten police patrol units.

Since certain heuristic approaches are what the Nigerian Police uses to deploy a crime preventive police patrol force to a number of precincts or hotspots, this may always not guarantee the maximum crime intercepts in the various precincts. The utilization of dynamic programming in resolving operations research problem always guarantees optimality (Tongo 2010 and Curtin et al 2007). Hence we can be assured that the 0.0317 cumulative weighted probability of police patrol initiated intercept obtained from the eight precincts in this study is the best value that any heuristic method of allocation will ever produce.Because of the superiority of dynamic programming over any heuristic approach, it is recommended that efforts towards the use of dynamic programming in the deployment of crime preventive patrol units to various region should be employed by the Nigerian police in general and in particular, Benin City Police Command Headquarter.Though the manual computation may become very difficult as the number of precincts and patrol units increases, computer packages can be used for such computations. Hence, this study can be extended to wider coverage of Benin City and additional assumptions can be introduced to stimulate the model. This is recommended for further research.

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