OPTIMUM ALLOCATION OF POLICE PATROLS IN AN ERS USING STOCHASTIC SIMULATION BASED ON A PERFORMANCE RESTRICTION

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ABSTRACT

Our research analyzes actual operating strategies of a public safety Emergency Response System (ERS) in a large city in Mexico integrating a sixth police district to previously published research composed of five districts out of a total of eight in the city. The research procedure firstly characterizes the demand for service and processes associated with the patrols' response and utilization during the attention of historic calls. Subsequently, we created a stochastic simulation model to emulate current ERS's patrols deployment strategies. After validating the model, we then generated a scenario with the restricted and optimized response time of three minutes maximum. Lastly, the minimum numbers of police patrols, required to provide the ideal response time for each police quadrant in every district, were obtained. Results reflect that the minimum required numbers of police patrols to provide an acceptable service level are viable.

Keywords: Police patrols allocation, Emergency Response System, Response time

INTRODUCTION

According to the 2014 annual Perception and Victimization National Poll (ENVIPE) on public safety in Mexico, the average perception of unsafe public environment was 73.3% among the population of 18 years old and older in all states, which represents an increment of 1% over last year's statistic. Furthermore, this source also establishes that on average 33.9 % of households in Mexico registered at least one victim of crime. These statistics are extremely alarming and unacceptable for any nation that claims to have peaceful living conditions. As part of the academic community, we strive to contribute with scientific analyses and operating strategies for the optimum allocation of police patrols to meet the international response time of three minutes maximum (NACCJ, 1973), and assist in the prevention and control of crime as well as in the custody of persons affecting the state of law.

The function of public safety Emergency Response Systems (ERS) is of essential relevance given that they are responsible for maintaining safety and well being of society (Zaki, Cheng, and Parker, 1997). Furthermore, Adler et al. (2013), state that ERS must provide an acceptable service level in order to assure public safety and security. Service level for ERS is most commonly related to its key performance parameter *response time* (Surkis, Gordon and Hauser, 1970), which is defined by Stevens (1980) and D'Amico et al. (2002), as the time interval between answering a call for emergency service and the arrival of the unit to the location where it is required.

Our research continues prior analyses developed by Holguin-De La Cruz (2014) integrating a 6th police district in an ERS from a large city in Mexico with a total of eight districts. The objectives of this ongoing research have been maintained which include:

(1) characterization of demand for service and service performance parameters,

(2) modeling ideal present conditions identified as Basic Proposal scenario,

(3) modeling scenario with 3 minutes maximum response time restriction (NACCJ, 1973),

(4) identify ideal patrol inventory levels for police quadrants, and

(5) identify areas of opportunity for improvement. The utilized software in our research was Pro Model 2010.

The sixth district incorporated in this research is located in the central Southeast of the city and it is composed of medium density residential, commercial and industrial land use recently developed. According to INEGI (2010), the number of inhabitants in the city exceeded 1.3 million and its urban surface was larger than 350 Km^2. Our research considers data obtained from 552 continuous hours of the ERS, which registered the demand for service and the times associated with the deployment of patrols. In the city's ERS, a police district is composed of typically four quadrants and every quadrant of four police patrolling zones. Ideally, a patrol is assigned to one patrolling zone; however, they often have more zones to patrol.

LITERATURE REVIEW

Zaki, Cheng and Parker (1997) identify the problem of determining the optimal allocation of personnel and equipment capable of minimizing the response time of the emergency service units to, or under, a specific value as one of the approaches to optimize an Emergency Service System. Since the 1960s the academic areas of Operations Research and Management Sciences have usually contributed with prescriptive models that improve the efficiency of emergency response systems (Green and Kolesar, 2004). Common methodologies utilized to identify alternative solutions to improve ERS performance include queuing models (Green and Kolesar, 2004), shortest path algorithm (Adler et al., 2013), hypercube model (D'Amico et al., 2002; Takeda et al., 2007), mathematical programming (Yang et al., 2015), and stochastic simulation (Zaki et al., 1997; Campbell et al., 2008; Brooks et al., 2011; Zhang and Brown, 2013, 2014; Wu et al., 2014). The processes involved in a safety ERS are presented in Figure 1 (Maxfield ,1982; Zaki et al., 1997; and Green and Kolesar, 2004).

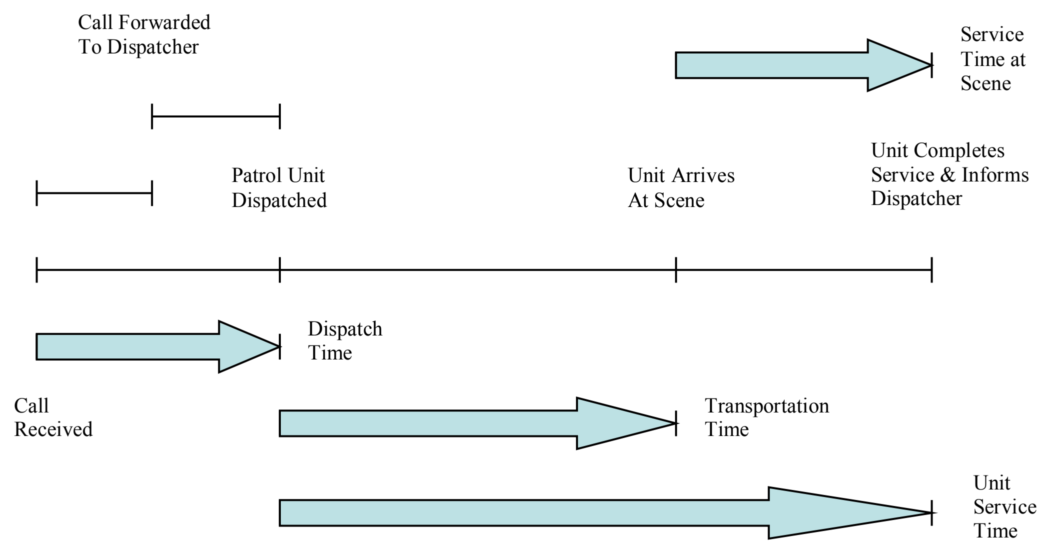

Figure 1. Sequence of Events in a Safety ERS

METHODOLOGY AND CASE STUDY

As explained before, this research integrates a 6th police district to previous research results of five police districts. Considering that a police district is composed of typically four police quadrants, our research approach is based on modeling police quadrants independently. We simulated the four police quadrants integrated in the 6th police district based on probability distributions of the service demand and patrol service processes of the four patrolling zones integrating each quadrant. The modeling time was ten replicates of 552 hours corresponding to the time period of the data.

Our research integrates two modeling scenarios. The first scenario is identified as Basic Proposal of Actual operations (BP-Actual). The second scenario, identified as Response Time of Three Minutes (RT3M), integrates the performance requirement restriction and will assist on the identification of the adequate number of police patrols assuming perfectible and realistic service processes supported with an adequate level of resources in the dispatch and deployment of patrols. Both scenarios allocate one dedicated patrol *P* per patrolling zone, and four additional back up patrols *B* available by priority for utilization evaluation purpose. Consequently, the utilization statistics of back up patrols are considered as indicators of the number of patrols required for every police quadrant to meet the ideal reference response time of three minutes maximum to a given service level. The function of back up patrols is to become available for patrolling and attending calls for service if a dedicated patrol is busy attending a call. Based on this operating strategy, every police quadrant integrates:

P_{dj} = Dedicated patrol *d* for patrolling zone *j*, *d*=1 to 4, and *j*=1 to 4, and

B_{ij} = Back up inventory patrol *i* assisting any patrolling zone *j*, *i*=1 to 4, and *j*=1 to 4

Back-up Patrol Usage Priority: *i*=1 > *i*=2 > *i*=3 > *i*=4

RESULTS

In this section, we integrate the characterization and simulation results of the sixth police district to prior published results. The characterization of parameters Inter arrival Time, Response Time and Patrol Busy Time at the Location of Event are illustrated in Table 1. In this table we can observe that Inter arrival Time is primarily characterized by Exponential (52%), Gamma (20%) and Lognormal (20%) distributions. Likewise, for the Response Time parameter we identify that it is mainly defined by Lognormal (81%) distributions. On the other hand, the parameter Patrol Busy Time is described by Lognormal (48%), Exponential (27%) and Gamma (19%) distributions.

Table 1. Characterization of Arrivals and Service of the City's ERS

Parameter	D_k[1]	Probability Distributions (95% C.I.)							Total
		Exponential	Gamma	Loglogistic	Lognormal	Normal J-T	Normal	Weibull	
Interarrival Time	D_1	30	9		7			2	48
	D_2	41	6		1				48
	D_3	27	6		9			6	48
	D_4	36			12				48
	D_5	1	21		14			12	48
	D_6	17	16		15				48
Response Time	D_1			3	13	3		2	21
	D_2				12				12
	D_3		3		9				12
	D_4	1	1		9		1		12
	D_5		1		11				12
	D_6				12				12

Patrol Busy Time at L[2]	D_1	6	4	3	7	1			21
	D_2	6	2		4				12
	D_3	4	1		7				12
	D_4	2	7		3				12
	D_5	4			7			1	12
	D_6		1		11				12
Total		175	78	6	163	4	1	23	450

[1] = (D_k) Police District k

[2] = (L) Location of Event

A narrative description of a sample CDF for only urgent (Priority 1) calls in one quadrant of the 6th district is as follows:

(1) less than 1% of the calls meet the 3 minutes maximum response time international reference,

(2) 80% of the calls have a response time of 19.23 minutes maximum,

(3) 95% of the calls have a response time of 34.3 minutes maximum, and

(4) 99% of the calls have a response time of 60 minutes maximum. These statistics are significantly high and un appropriate.

The simulation results of averages of ten replicates of the 552 hours (23 days) run are presented in Table 2. Based on the ANTU and AU parameters reported for both scenarios, it is evident that dedicated patrols are not capable of absorbing all service demand. Furthermore, this table also reflects that at least back up patrols B_{1j} are not minimally but significantly utilized in all six districts. Nonetheless, utilization of subsequent back up patrols is observed covering a decreasing portion of the demand.

Evaluating the performance parameter *Average Number of Times Used* (ANTU) in Table 2 for back up patrols in the BP-Actual scenario of all six police districts we have the values of 49.3, 7.37, 2.27, and 1.61 respectively for B_{1j}, B_{2j}, B_{3j} and B_{4j}. These same ANTU averages for the RT3M scenario are 34.9, 3.84, 1.72, and 1.5 respectively for the same back up patrols. From comparing this parameter we can distinguish a decreased back up patrol utilization in scenario RT3M explained by the increased dedicated patrol availability in this scenario with optimized dispatch and transportation times.

In Figures 2 and 3 the Percent Average Utilization (%AU) and Average Number of Times Used (ANTU) are illustrated. Comparing %AU values between scenarios in the same district, Figure 2 shows a substantial gain of RT3M dedicated patrols in available time due to decreased dispatch and transportation times. In consequence, back up patrols are gradually less demanded. This effect is also noticed in Figure 3 where the Average Number of Times Used (ANTU) parameter is increased for dedicated patrols in the RT3M scenario. Contrastingly, for back up patrols, Figure 3 illustrates for RT3M scenario an opposite behavior of decreased usage given that service demand is first attended by the dedicated patrols with more available time.

Table 2. Simulation Results by Scenario: District Comparisons of Quadrant Averages by Performance Parameters

D_k[1]	Scenario	Parameter	Dedicated Patrols				Inventory Back up Patrols			
			P_{11}	P_{22}	P_{33}	P_{44}	B_{1j}	B_{2j}	B_{3j}	B_{4j}
D_1	BP-Actual	ANTU[2]	148.28	129.83	126.48	103.23	64.68	11.58	3.38	1.63
		ATPU[3]	24.70	24.41	23.87	24.23	24.05	25.12	22.38	27.83
		% AU[4]	10.83	9.43	9.01	7.36	4.66	0.83	0.22	0.13
	RT3M	ANTU	154.15	133.80	131.18	107.28	45.75	5.60	1.60	1.30
		ATPU	14.89	15.32	14.36	15.37	14.66	16.42	18.43	17.05
		% AU	6.91	6.17	5.64	4.91	2.02	0.25	0.08	0.07
D_2	BP-Actual	ANTU	131.10	139.70	157.38	161.65	64.33	7.45	2.03	1.68
		ATPU	22.82	22.91	22.51	22.49	22.52	25.06	26.74	27.19
		% AU	8.94	9.60	10.68	10.90	4.32	0.51	0.14	0.12
	RT3M	ANTU	136.33	145.23	165.38	170.38	45.15	3.53	1.70	1.58
		ATPU	14.26	14.54	14.38	14.18	14.48	16.76	15.13	16.59
		% AU	5.89	6.38	7.14	7.23	1.98	0.17	0.07	0.07
D_3	BP-Actual	ANTU	105.70	127.03	116.75	132.48	46.40	5.78	1.75	1.53
		ATPU	20.09	19.78	19.31	19.70	20.22	20.42	21.91	23.93
		% AU	6.28	7.53	6.69	7.71	2.71	0.33	0.11	0.10
	RT3M	ANTU	100.38	129.33	119.28	141.45	32.45	3.25	1.70	1.58
		ATPU	13.43	13.61	12.95	13.54	13.42	14.03	14.88	15.50
		% AU	3.97	5.27	4.66	5.61	1.27	0.13	0.07	0.07
D_4	BP-Actual	ANTU	36.00	30.60	46.93	37.93	5.78	1.53	1.65	1.55
		ATPU	28.16	29.93	29.18	31.09	31.28	32.12	32.07	27.16
		% AU	3.10	2.22	3.76	3.61	0.53	0.14	0.15	0.12
	RT3M	ANTU	35.45	32.83	48.38	39.98	4.73	1.45	1.65	1.40
		ATPU	21.77	19.13	19.73	19.12	17.70	22.50	22.02	19.56
		% AU	2.39	1.71	2.68	2.27	0.26	0.09	0.10	0.09
D_5	BP-Actual	ANTU	127.38	122.23	160.10	141.78	74.78	12.95	2.80	1.75
		ATPU	24.75	25.49	24.88	24.71	25.03	24.14	22.73	27.98
		% AU	9.54	9.47	12.04	10.62	5.67	0.93	0.18	0.13
	RT3M	ANTU	127.03	124.28	170.15	153.15	56.70	6.45	1.98	1.60
		ATPU	16.61	16.32	16.51	16.19	16.91	15.80	16.68	21.84
		% AU	6.34	6.15	8.45	7.45	2.93	0.33	0.09	0.09
D_6	BP-Actual	ANTU	95.70	93.63	95.60	92.83	39.85	4.98	2.03	1.55
		ATPU	33.93	33.08	33.52	34.34	34.84	32.24	36.04	41.26
		% AU	9.81	9.36	9.68	9.62	4.19	0.50	0.20	0.18
	RT3M	ANTU	100.98	95.20	93.55	97.13	24.73	2.80	1.73	1.55
		ATPU	19.12	18.81	18.69	19.33	19.82	24.34	18.53	26.74
		% AU	5.81	5.39	5.26	5.68	1.46	0.18	0.09	0.11

[1] = (D_k) Police District *k*

[2] = (ANTU) Average Number of Times Used (From 4 Quadrants)

[3] = (ATPU) Average Time per Usage (From 4 Quadrants): Transportation Time + Service Time at Location

[4] = (%AU) Average Percent Utilization of Patrol Time (From 4 Quadrants)

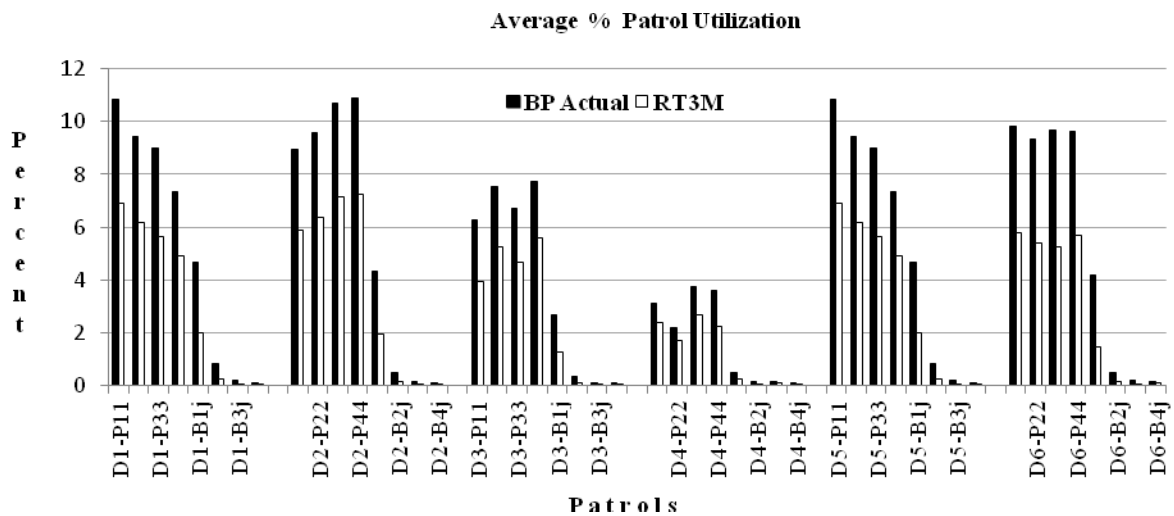

Figure 2. Average % Patrol Utilization by Patrol for Districts D_1, D_2, D_3, D_4, D_5 and D_6

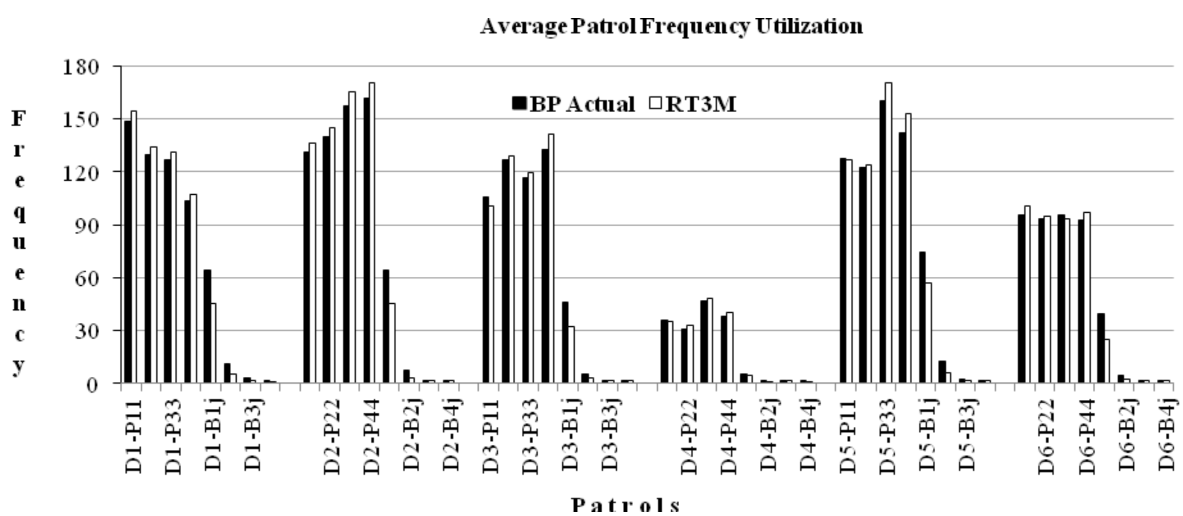

Figure 3. Average Frequency Utilization by Patrol for Districts D_1, D_2, D_3, D_4, D_5 and D_6

In determining the average ideal number of police patrols for every police district, we propose to include a back up patrol based on two reference initial criteria: (C1) if at least covers 1% of the total demand, or (C2) if it serves at least two events on average within a time interval (23 days in this case). The recommended average ideal number of patrols based on results from RT3M scenario are: for D_1, D_2, D_3, D_5 and D_6 (C1=1, C2=2), and for D_4 (C1=0, C2=1).

CONCLUSION

Through stochastic simulation actual operational strategies can accurately be reproduced and modified to generate proposed operating strategies based on performance requirements. This is very instrumental at evaluating potential required resource levels such as the number of patrols to geographically allocate in an ERS to meet an ideal expected and demanded performance.

We continue to confirm viable recommended operational strategies that demand a realistic number of one to two additional police patrols in every police quadrant of the 6th and the previous five districts. However, these results are only valid if radical basic improvements are implemented towards: (1) redistricting considering appropriate size and shape of patrolling zones, only four zones per quadrant and only four quadrants per district, (2) allocating one dedicated patrol to every patrolling zone, (3) providing required back up patrols for every quadrant to reach the maximum response time of three minutes when dedicated patrols are busy as a performance requirement, (4) minimizing dispatch and transportation times by providing resources and training, considering street grid infrastructure, safe maximum transportation speeds, and maximum patrol zone size to support the maximum response time of three minutes, and (5) monitoring real time patrol positioning with GPS technology as a tool for patrol dynamic allocation and supervision to validate geographic positioning.

Our research allocates greater value to a safe environment than to the cost of designing, configuring and operating an efficient ERS system able to meet a performance minimum requirement. We consider that a cultural change is necessary in all parts of society to share the previous perspective and leave behind the inadequate, traditional and unjust accepted design principle of limited resources and known or expected unsatisfactory performance to those more vulnerable.

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