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# Determining Ideal Number of Police Patrols to Meet Reference Response Time Using Stochastic Simulation

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***Abstract:*** *Mexico has experienced a drastic insecurity environment in the last decade due to multiple national and international factors. In this regard, public safety Emergency Response Systems (ERS) have the potential of effectively combat and deter crime through rapid and coordinated strategies. Utilizing stochastic simulation, our research focuses on determining an ideal number of police patrols to be allocated to a public safety Emergency Response System (ERS) in order to comply with a maximum international reference response time as a strategy to deter and combat crime in a large city in Mexico. The city´s ERS is composed by eight police districts, and this research incorporates the analysis of only half of the 7th police district to previously published results of six districts, given that this particular district is integrated by eight police quadrants, as opposed to only four adjacent quadrants found in a regular police district. Simulation scenarios include actual and proposed operating strategies of a police quadrant considering one dedicated patrol per patrolling zone plus an additional number of back up patrols. Results identify a feasible level of ideal back up patrols in all evaluated police districts. Recommendations are provided to reconsider redistricting strategies to assist the patrol deployment strategy.*
***Keywords:*** *Police patrols allocation, public safety emergency response systems, response time*

## I. Introduction

The perception of public insecurity levels in Mexico among citizens of 18 years old and older was 73.2% reported by the 2015 annual Perception and Victimization National Poll, ENVIPE [1]. This statistic is only 0.1% lower than its value last year and the second highest in the last five years. Moreover, this reference establishes that 33.2 % of the Mexican households denounced at least one victim of crime, which represents a practically equal level of 33.9% in the previous year. These alarming statistics demand urgent action to combat crime based on robust and efficient strategies involving all levels of government, society, and counterparts from the international community, since this problem is rooted in an international context, and must never be considered as a status quo.

Public safety Emergency Response Systems (ERS) have the crucial role in our communities of preserving peaceful and wellbeing conditions, as it is established by Zaki, Cheng and Parker [2]. To achieve this goal, ERS are required to offer adequate service levels [3] often measured by the key performance parameter of *response time* [4], which is measured from the answering time of a call to the arriving time of the unit to the event's location [5] [6]. However, although the ideal maximum response time of 3 minutes to attend urgent events has been identified in the US [7], police response times often exceed this limit in developed countries, with less optimistic scenarios in underdeveloped countries.

This research contributes with the evaluation of the 7th police district out of a total of eight districts in a large city in Mexico and previously published results [8] corresponding to the primary six police districts are integrated in this article. Given the extraordinarily larger geographic area of 7th district compared to the other six districts, and its consolidation of eight police quadrants instead of only four of a regular district, our analysis only considers four adjacent quadrants of the 7th district. Similarly to the evaluation of the other six police districts, this research follows the same sequence of analysis including: (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 [7], (4) identify ideal patrol inventory levels for police quadrants, and (5) identify areas of opportunity for improvement. The simulation software utilized by our research was ProModel 2011.

The relative location of the evaluated portion of the 7th police district corresponds to an approximate centroid of the urban grid, integrated in a squared like form. Its population density is considered to be medium high compared to the other police districts, and its land use integrates residential, commercial and industrial settlements. The evaluated city registered a number of inhabitants above 1.3 million [9], and an estimated area of 350 $km^2$. The city's ERS provided historical data of calls for service registered in 552 hours.

## II. Literature Review

Patrol response times can be identified as a function of several major factors including: (1) total number of police patrols available, (2) locations of patrols in relation to the proximity of the events, (3) police patrols allocation to a given area typically identified as districts, quadrants and patrolling zones, (4) traveling route from patrol location to the location of the event, (5) design of the patrolling areas in terms of shape and size, (5) geography of the patrolling area, (6) traffic, and (7) urban infrastructure. Our research focuses on identifying the ideal allocation of police patrols to a given area in order to meet the international reference response time of three minutes maximum established in the USA by the National advisory commission on criminal justice standards and goals: Task force on police [7].

The problem our research is trying to solve is identified in the literature as defining the ideal allocation of resources such as personnel and equipment which allow the minimization of the emergency service response time to a given target time or better [2]. Among the methodologies found in the literature that have assisted towards the improvement in the performance of Emergency Response Systems are queuing models [10], route optimization algorithms such as the shortest path [3], the hypercube model [11], mathematical programming [12], and discrete event stochastic simulation [13][14][15][16]. A brief review of specific references where discrete event simulation has been used in the optimization of ERS operations is offered in the following paragraph.

Zhang et al. [17] emphasizes the key performance parameter *response time* to be included among the most typical performance measures of a police patrol service, and investigates the service quality in police patrol service systems with alternate moderate under-staffed and over-staffed periods via simulation. Zhang and Brown [13], utilize an agent-based simulation model to evaluate police redistricting strategies as one optimizing factor to improve average *response time*. Additionally, Zhang and Brown [14] applied simulated annealing to optimize police patrol district design and evaluated performance of alternatives including average *response time* applying a discrete event simulation model. In an emergency medical response system we can identify the same optimization problem of improving *response time*. Aboueljinane et al. [18] state that deployment is the most studied problem in emergency medical services design and operation, and identify capacity requirements including number of rescue teams needed to increase the percentage of events that are served within an ideal *response time*.

## III. Methodology

The simulation models one police quadrant at a time of the four quadrants in a police district, and reports results averages of the four quadrants, given the article's length limits. Emulating the time period of the data sample, the simulation run time was 552 hours using ten replicates. For comparison purposes, this research integrates results of the 7$^{th}$ police district to the previously published results of the six districts. Characterized probabilistic times of relevant processes were utilized in our modeling efforts.

Two modeling scenarios were used in the simulation modeling. In our first scenario (BP-Actual), we reproduce current patrolling operating conditions except the number of police patrols that served a particular police quadrant. Although the ERS ideally allocates one *dedicated* police patrol P to each one of the four patrolling zones in a police quadrant, this guideline is not always possible to observe. However, this scenario includes not only one police patrol for each patrolling zone, but also four *back up* police patrols B as additional resources to be used by priority in the event that all dedicated patrols are being utilized in a given moment and a new call for service is received. The second scenario (RT3M) represents the ideal conditions that reproduce the optimum response time reference of three minutes maximum, mentioned before, and maintains all other factors constant.

The four additional *back up* patrols *B* are available by priority for utilization evaluation purpose. These statistics are then applied in the decision making process to propose an adequate number of back up patrols per quadrant within a police district in addition to the dedicated police patrols in order to reinforce complying with the ideal reference response time of three minutes maximum. Considering this resource configuration strategy, both simulation scenarios include:

$P_{dj}$ = 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: $i=1 > i=2 > i=3 > i=4$

## IV. Results

The probability characterizations of the ERS related processes and simulation results are presented in this section. In Table I it can be observed the frequency distribution of probability distributions that best characterized each one of the most relevant time parameters related to the deployment and utilization processes. For district seven we identify that *inter arrival times* are characterized by Gamma (39.5%), Lognormal (35.4 %), Exponential (12.5%), and Weibull (12.5%) distributions. Similarly, for our performance parameter *response* *time*, we observe that probability distribution Lognormal (100%) describes it. Lastly, the *patrol busy time* at the location of the event was found to be depicted primarily by Lognormal (91.6%), and Gamma (8.3%) distributions.

**Table I:** Characterization of Arrivals and Service of the City's ERS

| Parameter | $D_k$[1] | Probability Distributions (95% C.I.) | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | Exponential | Gamma | Log logistic | Lognormal | Normal J-T | Normal | Weibull | |
| Inter Arrival 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 |
| | $D_7$ | 6 | 19 | | 17 | | | 6 | 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 |
| | $D_7$ | | | | 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 |
| | $D_7$ | | 1 | | 11 | | | | 12 |
| Total | | 181 | 98 | 6 | 203 | 4 | 1 | 29 | 522 |

[1] = ($D_k$) Police District *k*
[2] = (L) Location of Event

An average CDF value for priority one calls of all four quadrants in district 7th for the 3 minute maximum response time was identified to be 2.17% only. Whereas corresponding averages of time response for the 20, 40, 60, 80, and 98 % CDF values are 5.64,7.28, 9.2, 12.5, and 28 minutes correspondingly. We considered this response time distribution has a considerable opportunity for improvement

Table II illustrates simulation results of police quadrant averages for every police district. Furthermore, the Police quadrant results represent averages of the ten 552 hr replicates. Focusing only on district's 7th results we can observe that for parameter ANTU in BP-Actual scenario, back up patrol $B_{1j}$ absorbed on average 41 calls for service, and likewise $B_{2j}$ contributed on average with the service of five events. These statistics are reflected the insufficient capacity of just the dedicated patrols in this district. This behavior has been observed as a constant in all evaluated police districts. Comparing the parameter ANTU for the RT3M scenario with the BP-Actual scenario within the same district seven, a significant decrease (33% and 42% respectively for $B_{1j}$ and $B_{2j}$) in the number of times used on average for these back up police patrols is identified. This difference is explained by an increase in capacity of all dedicated patrols $P_{dj}$ in RT3M due to their minimized utilization time during deployment.

**Table II:** 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 |
| **$D_7$** | **BP-Actual** | **ANTU** | 117.48 | 105.23 | 86.45 | 102.70 | 41.08 | 5.08 | 1.78 | 1.70 |
| | | **ATPU** | 26.79 | 27.17 | 27.01 | 27.93 | 28.27 | 27.60 | 35.28 | 31.38 |
| | | **% AU** | 8.28 | 7.51 | 6.26 | 7.31 | 2.92 | 0.37 | 0.15 | 0.12 |
| | **RT3M** | **ANTU** | 118.30 | 110.55 | 91.75 | 106.00 | 27.28 | 2.90 | 1.63 | 1.55 |
| | | **ATPU** | 14.89 | 15.12 | 15.71 | 15.28 | 15.37 | 18.40 | 20.55 | 23.08 |
| | | **% AU** | 5.23 | 5.04 | 4.28 | 4.81 | 1.25 | 0.14 | 0.08 | 0.10 |

[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)

Similarly, for the performance parameter percent average utilization of patrol, %AU, the change in behavior explained before for parameter ANTU, is also distinguished in Table 2 for both scenarios in % relative usage.
A graphical and historic representation of simulation results for police districts $D_1$ to $D_7$ is presented in Fig. 1 and 2, where performance parameters percent average utilization %AU, and average number of times used ANTU, are observed for the BP-Actual and RT3M scenarios.

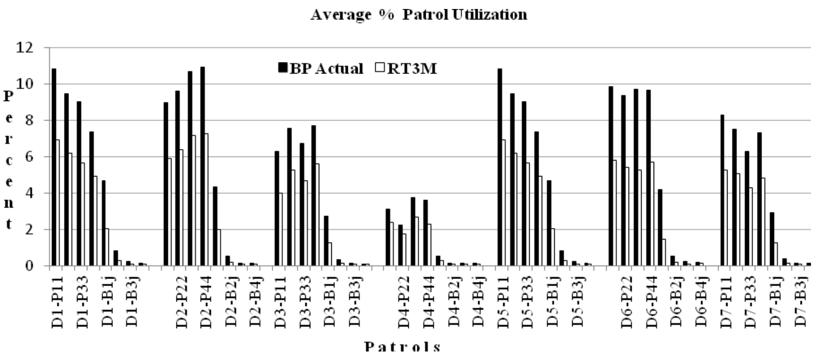


**Figure 1:** Average % Patrol Utilization by Patrol for Districts $D_1$, $D_2$, $D_3$, $D_4$, $D_5$, $D_6$ and $D_7$

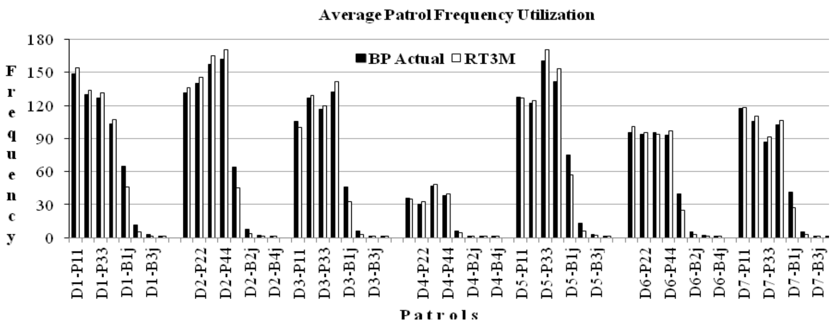


**Figure 2:** Average Frequency Utilization by Patrol for Districts $D_1$, $D_2$, $D_3$, $D_4$, $D_5$, $D_6$ and $D_7$

From these results several configurations of patrol allocation strategies can be identified as a function of the desired service level considering the patrol's restriction of being available at the moment of the call. The first allocation criterion could be based on the percent average utilization (%AU) parameter, deciding to allocate an additional back up patrol if the patrol´s %AU value reaches at least 1% of the demand for service in a given time period. Also, a second criterion to allocate an additional back up patrol $B_{ij}$ could be if this patrol serves on average two events within the 23 day time period. In Table III we present the ideal allocation of police patrols by police district and criterion based on police quadrants averages.

**Table III:** Ideal Average Number of Back up Patrols by Police District and Allocation Criterion

| District $D_k$ | No. of Back up Patrols by District Criterion 1 | No. of Back up Patrols by District Criterion 2 |
|---|---|---|
| $D_1$ | 4 | 8 |
| $D_2$ | 4 | 8 |
| $D_3$ | 4 | 8 |
| $D_4$ | 0 | 4 |
| $D_5$ | 4 | 8 |
| $D_6$ | 4 | 8 |
| $D_7$ | 4 | 8 |

## V. Conclusion

Results obtained for half of the 7th police district reflect that it ranks 5th considering the city's ERS demand for service. We believe prolonged response times could be minimized to the international response time reference of three minutes maximum by effectively and efficiently utilizing zone dedicated police patrols in every police quadrant, and with the provision of two to four back up patrols dedicated to each police quadrant in all police districts. We estimate that the main activities in the deployment process including the answering of calls for service, and transportation, could be significantly improved by configuring adequate and realistically reachable levels of resources. In addition, we recommend the revision of current police district designs to assist with appropriate patrolling zone geographic areas subjected to particular infrastructure and regulations such as maximum driving speeds.

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