Cal Poly

Police Operations Simulation

A Senior Project by Robert McGee

Technical Advisor: Dr. Curry

Robert McGee
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Abstract

In this report, the author explains the process of creating the Police Operations Simulation, shows step-by-step how it works, and statistically analyzes the results from SLOPD's own proposed and current schedules. The data-gathering from the department and the simulation itself will receive the bulk of the coverage in this report, followed by sample results from SLOPD and a business plan for future sale to other departments.

Using the given numbers, it appears that the proposed schedule will result in significantly improved coverage for the city of San Luis Obispo. While any increase in the number officers on patrol tends to be positively correlated with faster response times, the increase during peak times in particular has a dramatic effect on the response, and the overlap shift is a very effective way of utilizing planned overtime to increase coverage without increasing manpower.

Contents

Introduction

This report explains in detail the Police Operations Simulation senior project, performed in 2009-2010 by Robert J. McGee, with technical advising by Dr. Curry. The project includes extensive simulation work, using two months worth of call and response data from the San Luis Obispo Police Department (SLOPD), as well as statistical analysis, time studies of the data, operations research for some of the theory in the literature review, and Visual Basic and Excel programming.

The problem statement for the project is:

- Investigate feasible and improved schedules for officers in SLOPD to meet one or more of the following objective(s):
  - Maximize coverage during peak hours
  - Minimize officer shortages
  - Minimize response times
  - Minimize overtime

To accomplish the goals outlined by the problem statement, a simulation was constructed using ExtendSim 7.0, with historical data from 2008, in order to test all new proposed schedules. The simulation was constructed with the long-term goal of applying it to any police station simply by replacing the values with their own, in order to sell the use of the program to other departments looking to optimimize their schedules.

Background

SLOPD is considering changing its schedule to include more officers at different hours, and to include an "overlap shift" where officers from one shift begin duty several hours before the previous shift has ended, in addition to the current standard practice of planned overtime. Dr. Curry contacted Chief Linden, offering to use simulation and operations research to test proposed schedules for her. A copy of the proposal letter is below.

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SLOPD, Scheduling Study Proposal

Operations Research (OR), also known as Decision Science or the "science of better" can be used in the private and public sectors to deploy and allocate scare resources to their maximum benefit. Resource scheduling is one allocation problem that can be addressed with the methods of OR. An agency can specify an objective, for example minimizing officer-hour shortages, while meeting constraints such as the number of available officer-hours per shift. Mathematical models can simplify the task of scheduling, given accurate data, constraints, and a feasible objective.

As a faculty member of Cal Poly's Industrial and Manufacturing Engineering (IME) Department, I am interested in utilizing OR methods to help public agencies, while providing applied learning opportunities for students. I propose to conduct a confidential and exploratory scheduling study, in conjunction with Cal Poly IME senior student(s), to evaluate and propose alternatives to the current police officer schedule with the objective of maximizing police officer effectiveness, while meeting the needs of the community, SLOPD, and officer work-life conditions. I expect the study to be used as a senior project and possibly a research paper. Any data indentifying individuals will be redacted from resulting papers.

Specifically, I recommend undertaking research for the SLOPD to investigate feasible and improved schedules for officers to meet one or more of the following objective(s): maximize coverage during peak hours, minimize person-hour shortages per week and per day, minimize officer response times, or minimize overtime, while accounting for shift length, shift type (rotating vs. fixed), shift start times, officers per car, minimum officers on duty, and non-patrol duties (training, public service/education at schools, station duty, paperwork). In addition, the schedule will account for uncertain absences due to illness, injury, etc.

Based on a preliminary discussion with Chief Linden and Captain Parkinson, the study will analyze and attempt to optimize schedules under the following conditions:

- Current number of patrol units and system (3-12's from 7-7, with 8 hr payback day)
- An increase of 6 to 10 units at peak times.
- A platoon or squad system.

The study intends to provide the following analysis and results for SLOPD:

- Schedules to meet identified objectives subject to constraints.
- Compare resulting schedules under the three proposed scenarios in terms of objectives, work/life balance.
- Compare resulting schedules utilizing simulation model to demonstrate outcomes on officers, community, response times, and officer utilization.

I look forward to hearing from you and am excited about the prospect of working with your department.

Sincerely,

Barbara Curry, Ph.D.
Industrial and Manufacturing Engineering Department,
California Polytechnic State University, San Luis Obispo

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Cal Poly student Robert McGee agreed to take on this work as his senior project. The work consisted mainly of statistical analysis, simulation, and programming, with elements of operations research and time studies from historical data. Work began in Fall 2009 and is ready for completion in late Spring 2010. After the final results are presented to SLOPD, the data-sorting software, simulation, and results interpretation are to be offered for sale to other precincts.

Literature Review

While much of the information about SLOPD used by the author was provided in person or in emails by various department members, a general overview of the department can be found at http://www.ci.san-luis-obispo.ca.us/police/index.asp, the department's website. Here can be found useful information such as the Annual Report, a general non-technical overview of operations every year department history, information about personnel, and general crimes statistics for SLO.

SPILLMAN software used by the police is a product of Spillman Technologies. Their website, http://www.spillman.com/Home.php, includes helpful links to product literature and demo software. While the author was unable to use the demo software due to being a student, and not a member of any police force, the online literature was available for review, and proved helpful in interpreting the data from SLOPD. This included several white papers on the software.

Power Programming with VBA/Excel describes the process of Visual Basic coding in Excel, as well as the process of importing data from .txt files and other formats. This proved to be a vital reference in transferring the data from SPILLMAN to Excel for analysis; as explained during Methodology, the data was not immediately compatible, and had to be parsed into useful sections. Every line had to be written into a single string (a data type used by Visual Basic). Each time and duration note within the string had to be separated from the rest and sorted into the correct cell. Finally, the program had to be able to filter out duplicate and blank entries from several thousand lines of data, then provide useful information such as inter-arrival times that were not specifically noted in the data.

The features and history of ExtendSim 7 are given a broad overview in a paper simply entitled *EXTENDSIM 7* (Krahl, 2008). The paper opens by detailing the history of the Extend line of software, which is what is being used for this senior project. Released in 1988, Extend was the first graphical

simulation program to feature a hierarchal modeling structure and graphical block connections. ExtendSim also has its own database feature. A "block" is the named for the visual interface of a simulation component – for example, an activity block implements an activity, while a queue block holds entities in queue.

The hierarchy feature is necessary to reduce clutter in a graphical modeling environment. A single icon can represent a smaller model in and of itself. In this senior project, a hierarchal block is necessary to contain the large collection of Routing blocks and Set Property blocks for determining which of 110 possible types of calls any given crime will be.

The graphical interface allows a user to select the appropriate block from a library and place intuitively in the modeling environment, then connecting it to other blocks in the model. For example, in this senior project, the Activity block from the Item library simulates time-consuming processes such as dispatch and travel times; appropriate parameters, such as the mean and standard deviation values for a time distribution, are drawn from Lookup blocks from the Value library. The Lookup block is attached to a connector icon on the Activity block, represented graphically by a connector line.

The relational database built into ExtendSim 7, very similar to the one used in Access 2007 in the IME 312 class, allows the user to use a large amount of data without accessing external programs such as Access or Excel. This feature is critical to this project, as each of the 110 call types takes a different amount of time to resolve. The user can store the parameters of a distribution within the database, then access the entire table of values from an activity block. An Activity block can read the Crime_Type property of an incoming Call Entity, then retrieve the appropriate *mu* and *sigma* value from the database for a lognormal distribution of dispatch and resolution time.

A nontechnical overview of the application of simulation technology to police forces is given in *A Simulation Model of Patrol Operations: Executive Summary* (Kolesar, 1975). The paper was written to

help officers in the New York Police Department understand what a simulation can do for them, and when it would be appropriate to use. The simulation described in the paper was designed to evaluate changes in deployment policies, specifically in patrol areas and dispatch procedures.

Just like the Response Time Project, *A Simulation Model* notes that it does not simulate the exact path each car drives in order to respond to a time. Instead, historical data gives a statistical distribution for the response time. In *A Simulation Model,* that distribution varies according to the region of the call. San Luis Obispo is a small enough town that response times are quite consistent regardless of the time or nature of the call (see appendix for these values). Although the SLOPD divides the town into three regions, for the purposes of the simulation a single distribution for each time period accurately describes the travel time. More importantly, both the Response Time Project and *A Simulation Model* require that resolution time vary by the nature of the call. These times determined how long an officer in engaged in a specific activity, and therefore unavailable for other tasks; as more calls come in, the lower number of available officers affects the total response time. To further increase accuracy in comparison with the real world, the simulation can accurately represent the number of officers responding to a particular type of crime, and officers can leave a particular low-level crime to respond to a higher-priority call (i.e. renege). These changes affect the total system time, which can be compared to the effects of other changes. In short, the primary metrics measured by the simulation will be response times, queuing delays, and patrol car activity/availability. Changes in scheduling and resources will affect these metrics, the results of which will be reported in the simulation.

Systems Simulation: The Shortest Route to Applications is a web-based reference tool for simulation and discrete-event analysis. The site has been online since 1994, and updated annually since by the author, Dr. Hossein Arsham. It describes simulation both in general terms and through the use of specific examples. For instance, dynamic systems are those where the conditions change over time.

The police simulation is a dynamic system, since the number of calls, the rate of call arrival, and the number of officers available all change depending on the time of day and day of the week. An "epoch" is a specific point in time. In addition to its own simulation resources and links to other resources, the site's list of definitions for simulation terms is well-written enough that most can be easily explained to laypeople, such as the police department, who need to understand how the simulation can benefit them and why the results can be trusted.

Stochastic Scheduling (Niño-Mora, 2005) gives a detailed overview of stochastic scheduling – modeling situations where "scarce service resources must be allocated over time to jobs with random features vying for their attention," as described in its abstract. This is a general description of the SLOPD Response Time Project, allocating a limited number of resources (officers, squad cars, detectives, etc.) to a set number of timeslots to respond to a number of incidents which varies depending on its timeslot. In this model, the time to dispatch, the time for officers to arrive, and the time to deal with the incident are all variable; this is the process of pushing a job through a series of three stochastic processes to find the total time to completion.

While one of the project's aims is to reduce *flowtime* (the expected time) of dispatching and response, the article also mentions minimizing *makespan,* the time it takes to finish the last job. The necessity of minimizing *makespan* occurs when different jobs with different priorities could come in at any time. In police work, officers will be dispatched to a serious crime before a minor one. Similarly, an officer might abandon one minor task in progress to respond to one requiring backup immediately. The article discusses the optimal strategies in the queue

depending on the sorts of rules it follows with regard to priority, abandonment, reneging and balking.

The third section of the article is the most important one: the "Queuing Scheduling Control Models" chapter discusses the optimum model where new tasks, in addition to taking variable amounts of time to complete, also arrive at random epochs over time. An "epoch" is a specific point in time – for example, if the first call arrives three minutes after the simulation starts, the simulation would define that as the epoch t_1 = 3 minutes. The time between relative epochs is the inter-arrival rate. While these arrival rates can be predicted using statistical methods, the model needs to be equipped to perform within a certain set of possible states. If a normal day sees one call every twenty minutes or so, then one day suddenly sees a call every two minutes for some period of time, SLOPD needs to know ahead of time if the existing rules for responding to the input can handle it – that is, keep the queues under a certain length. The model will need to be able to handle as little as one dispatcher, or as many as four. These dispatchers must be able to direct the efforts of as few as four cars on slow days, or as many as two or three hundred officers on holidays. Service time will vary at each step, but if the queue gets too long, then either the model is suboptimum, or the SLOPD cannot handle the event in question.

Stochastic Storage Processes: Queues, Insurance Risk, Dams, and Data Communication (2nd Edition) is a monograph on several types of stochastic queuing processes, as outlined in the title. It is notably more math-intensive than a lot of other sources, frequently forgoing a textual, qualitative explanation of concepts. The chapter important to this project is that of insurance risk. In the police simulation, one of the department's desires is to have an accurate simulation of major exigencies such

as riots – that is, any situation in which the department has to call on outside resources without forewarning. Insurance risk is the same concept, but with money instead of police officers. The “risk reserve” is the amount of money currently in the system, which changes according to income and outgoing payments; for the police, the number of officers not engaged in a specific task function as the risk reserve, and that number changes as calls arrive and as they are resolved.

When the risk reserve in an insurance problem is depleted, the company is bankrupt. When the reserve of officers becomes negative, the station must call in support from off-duty officers, or even (in extreme cases) other police departments in the county. This is known as the “ruin event”. For insurance companies, the company must invest a large enough initial reserve to avoid going below zero money. For the police problem, the department must avoid going below zero available officers in during a duty cycle in order to avoid the use of off-duty and out-of-town officers. While SLOPD already calls in extra officers ahead of time for known events such as holidays, this project is focused on avoiding “ruin” during day-to-day operation. The department wants to see if a given schedule includes enough officers to deal with incoming calls, even during unusually active days.

Fundamentals of Modern Statistical Methods: Substantially Improving Power and Accuracy is a well-written description of the statistical processes that will be utilized in this simulation. Key here is the explanation of the Central Limit Theorem, which is vital to the final presentation of the data. After a “reasonably large” series of samples, the mean Response Times of all samples should form a normal distribution. This makes hypothesis testing much easier, since the author can compare two normal distributions from fifty trials of two different schedules represented as normal curves. These sample means will tend to be centered around the mean that the simulation is actually trying to find, giving reasonable confidence in the accuracy of the hypothesis test.

Another useful section of *Fundamentals of Modern Statistical Methods* are the descriptions of hypothesis testing and power and sample size. During the analysis of results, the metrics of the police simulation are plotted as normal distributions and undergo hypothesis testing to see if a statistically significant difference exists. Power and sample size calculations determine the likelihood of a Type II error – failing to find a difference when in fact one exists. Both processes is described more fully in the section where they are used.

Foundations of Queuing Theory describes, appropriately enough, the mathematics of queues. The police simulation will include several queues, each leading to one or more servers, and proper understanding of the principals involved will be necessary to construct a working system. Each queue is an *M/LN/s* queue, where the input (*M*) is a Markovian input (exponentially distributed inter-arrival times)

$$a(u) = \lambda e^{-\lambda u}$$

where $0 < \lambda < inf$. The number of arrivals in a given time interval (0, *t*] will have a Poisson distribution with mean λt. The service time (*LN*) is lognormal-distributed times, never less than zero. Service discipline is priority-based First-In, First Out; that is, the highest priority call is served first, and ties are served in the order of arrival. The number of servers (*s*) varies depending on the schedule and activity; it is the effect of this variable on the system as a whole that will be tested in the simulation.

A Queuing-Linear Programming Approach to Scheduling Police Patrol Cars is a linear-programming take on police schedule optimization. It serves as the guide for several parts of the analysis. While linear programming is not as powerful as simulation given the uncertainties in this project, it can be used as an aid to the final result.

Unfortunately, *A Queuing-Linear Programming Approach* makes many assumptions that this project does not. For example, the paper simply assumes a constant average time for police response, and that only one officer responds to each call. The lack of a stochastic element makes it impossible to stress-test the system response for variable demand over time. It even dispenses with the use of a priority system for each call, sticking with the less complex *M/M/s* queuing model. With the power of computer simulations, such assumptions are not necessary, and the final simulation is even able to generate a variable number of responders to each type of crime, within certain parameters.

Design: Data Gathering

SLOPD keeps its data from dispatch and police transmitters on SPILLMAN software, specifically developed for police departments. They upgraded to this software several years ago, and intend to use it for at least a few more years.

Gathering the data from SPILLMAN was problematic. It was not directly transferable to Excel, Minitab, or any other easily-used spreadsheet software. Instead, all data was transferred into .txt files, which looked like this:

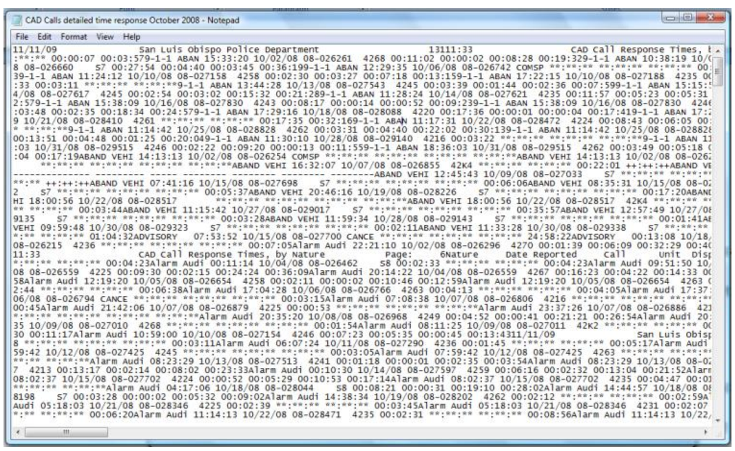


Figure 1 - SPILLMAN Data

The results were not any cleaner on Excel or Minitab, and the auto-format features of Excel did not satisfactorily sort out the data. It was necessary to create a Visual Basic program which would identify the elements of the data and paste it onto a spreadsheet in a useable format for statistical analysis. Although the author had to do this personally, Spillman Technologies would transfer data from one system to another for a paying customer such as a police department. (Spillman)

The end result of the data extraction was a series of Excel spreadsheets. Some listed the frequency and time of occurrence of each type of crime; others listed specific information about each

call. These are not included in the final report due to their length – February 2008 alone is over 4,700 lines of data. Instead, samples will be shown as necessary. Two are included below.

The first sample is off the frequency of crime by day and time for the year 2008. This sample is of Residential Burglaries:

Table 1 - Residential Burglaries

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
00:00-00:59	1	0	1	1	0	0	1	4
01:00-01:59	0	0	1	1	2	1	1	6
02:00-02:59	1	0	1	0	0	1	1	4
03:00-03:59	1	0	1	1	0	2	0	5
04:00-04:59	1	0	0	0	0	0	0	1
05:00-05:59	0	0	0	0	0	0	1	1
06:00-06:59	0	0	0	0	1	0	0	1
07:00-07:59	0	0	0	1	1	0	0	2
08:00-08:59	1	0	2	1	0	1	0	5
09:00-09:59	3	2	0	1	4	1	2	13
10:00-10:59	3	3	0	1	3	0	4	14
11:00-11:59	6	3	0	3	1	3	1	17
12:00-12:59	1	2	3	5	0	2	2	15
13:00-13:59	4	2	3	0	3	1	1	14
14:00-14:59	1	2	4	3	1	1	0	12
15:00-15:59	4	5	3	1	3	0	1	17
16:00-16:59	2	4	2	1	2	2	2	15
17:00-17:59	6	3	2	4	3	0	2	20
18:00-18:59	3	0	1	1	1	1	2	9
19:00-19:59	2	3	1	1	1	3	3	14
20:00-20:59	1	0	2	1	2	0	0	6
21:00-21:59	1	1	0	1	1	1	1	6
22:00-22:59	1	0	3	1	0	0	0	5
23:00-23:59	1	0	1	0	0	1	1	4
Total by Day|	44	30	31	29	29	21	26	210

This data was used both to construct the "Frequency of Crime by Type" figures for the simulation and, later, to check the accuracy of the outputs. There are 76 such charts of data, even though there are 110 types of dispatch output codes, because some data is recorded under the same category, or is not recorded as a "crime" – for instance, BOL (Be on Lookout) calls do not get recorded by frequency. (SLOPD, 2010).

The second type of file outputted by the SPILLMAN converter was the precise call history, a sample of which is below. The sample is for Alcohol Offenses, typically meaning public drunkenness. All times are on a 24-hour clock, meaning "1:52:36" is 1:52 AM.

Table 2 - Police Records Sample

Nature		Time	Date	Call Num	Unit	Dispatch	Travel	Scene
Alcohol	Of	1:52:46	2/1/2008	08-002741	4246	**:**:**	**:**:**	0:10:57
Alcohol	Of	1:52:46	2/1/2008	08-002741	4249	**:**:**	**:**:**	0:10:57
Alcohol	Of	1:52:46	2/1/2008	08-002741	4260	0:02:51	0:00:16	0:08:27
Alcohol	Of	1:52:46	2/1/2008	08-002741	S3	**:**:**	**:**:**	0:10:49
Alcohol	Of	20:33:54	2/1/2008	08-002793	E19	**:**:**	**:**:**	**:**:**
Alcohol	Of	20:33:54	2/1/2008	08-002793	SO2	0:06:55	--:--:--	0:08:32
Alcohol	Of	23:41:24	2/1/2008	08-002821	4249	--:--:--	0:00:37	0:37:48
Alcohol	Of	1:01:56	2/2/2008	08-002835	4216	0:18:05	0:03:11	0:13:40

Notice that there are duplicate entries. This represents one entry per responding unit, each identified by their own unit code. **:**:** and --:--:-- indicate non-recorded times. "Dispatch" indicates the amount of time a dispatcher spent communicating with a caller over the phone or an officer over the radio. Travel indicates the direct response time of the officer. Null entries in either Dispatch or Travel typically indicate the officer saw the offense in progress, rather than being dispatched directly. (SLOPD, 2010) In such cases, officers still report the case to dispatch, and the time is often recorded in another duplicate entry. "Scene" indicates the amount of time the officer spends resolving the crime.

Further sorting had to be completed before statistical analysis could begin. In order to accurately model the rate of incoming calls, duplicate and null entries had to be omitted. Incoming calls rates had to be varied by time period, requiring data *not* from that time period to be omitted. Still, each time period had to be large enough to have enough data points for a clean fit (Arsham). The final breakdown chosen was six-hour blocks from 02:00 to 08:00, 08:00 to 14:00, 14:00 to 20:00, and 20:00 to 02:00.

Below is a sample graph of the fitted rate of incoming calls from 20:00 Thursday to 02:00 Friday.

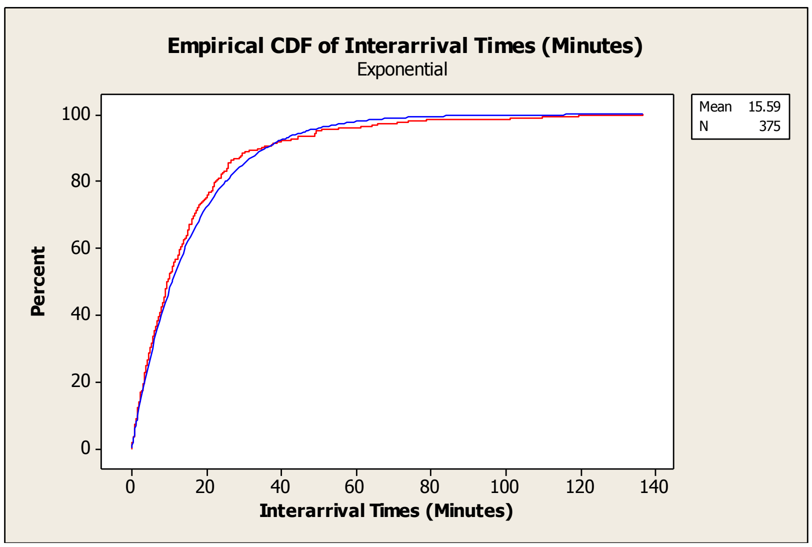


Figure 2 - Thursday 2008 20:00 - 02:00

While Minitab displays the results more cleanly, all distributions were found using EasyFit 5.3, an Excel Add-On which tested the fit of the data against numerous possible distributions and found the Exponential fit to be best. This is appropriate, as the Exponential distribution is frequently used to model inter-arrival rates, due to its "memory-less" properties. If a call has a 50% probability of arriving within five minutes, then, five minutes later, a call still has a 50% chance of arriving within the *next* five minutes. (Prabhu 1998, p. 14)

In addition to the numerical data, SLOPD also offered a list of Dispatch procedures. These included the typical number of officers assigned to a type of call, whether or not dispatchers were required to stay on the line with a caller, and the default priority of each type of call. Often, these values were varied *ad hoc* by the department, as different calls within the same technical category may have varying levels of severity. So, while the default priority of an Assault case might be 2 (high priority), and the number of officers sent by default might also be 2, the historical data indicates some flexibility in these values, which would later be modeled in the simulation. ExtendSim can change these properties at any time, so even once a crime has a certain Nature, its properties can be changed without affecting the default properties of that nature (Weiss 2008).

Lastly, the author personally observed operations on two occasions: first, in December of 2009, the author spent several hours in Dispatch, taking notes about procedures, interviewing dispatchers and officers, and observing the functionality of the software. These notes influenced the eventual construction of the simulation, resulting in a complex Dispatch function that will be detailed in a later section. Additionally, this was the first time the author received an in-person explanation, and live demonstration of SPILLMAN software, which facilitated understanding the raw data.

The second occasion of personal observation was in May 2010, when the author spent three hours in a ride-along with an officer. The author observed the responses to several calls, as well as the process of personally investigating events without instructions from dispatch – though the officer did report his own activities. Additionally, the author interviewed the officer about police operations in general, and response to dispatch in particular. All the information gathered during this ride-along resulted in a major redesign of the Officer Resource Assignment function, including the varying number of officers, the process of preemption, and the report-writing procedure.

Design: The Simulation

The Police simulation is divided into several phases: 1) The creation of a Call entity, 2) The assignment of Attributes to the Call, 3) The arrival of the Call into the Call Waiting Queue, 4) the processing of a Call in the Dispatch activity, 5) the assignment of Officer Resources to the Call, 6) the Travel processing activity, 7) the At Scene processing activity, and 8) Freeing Officer Resources and closure of the Call. This section will address each part of the process in detail.

Below is a screenshot of the entire simulation. As mentioned previously, ExtendSim is primarily a GUI-based language. Each white box represents a Hierarchal Block, which holds a sub-simulation of comparable complexity to a complete one. Screenshots of smaller places will be included and explained in the next section.

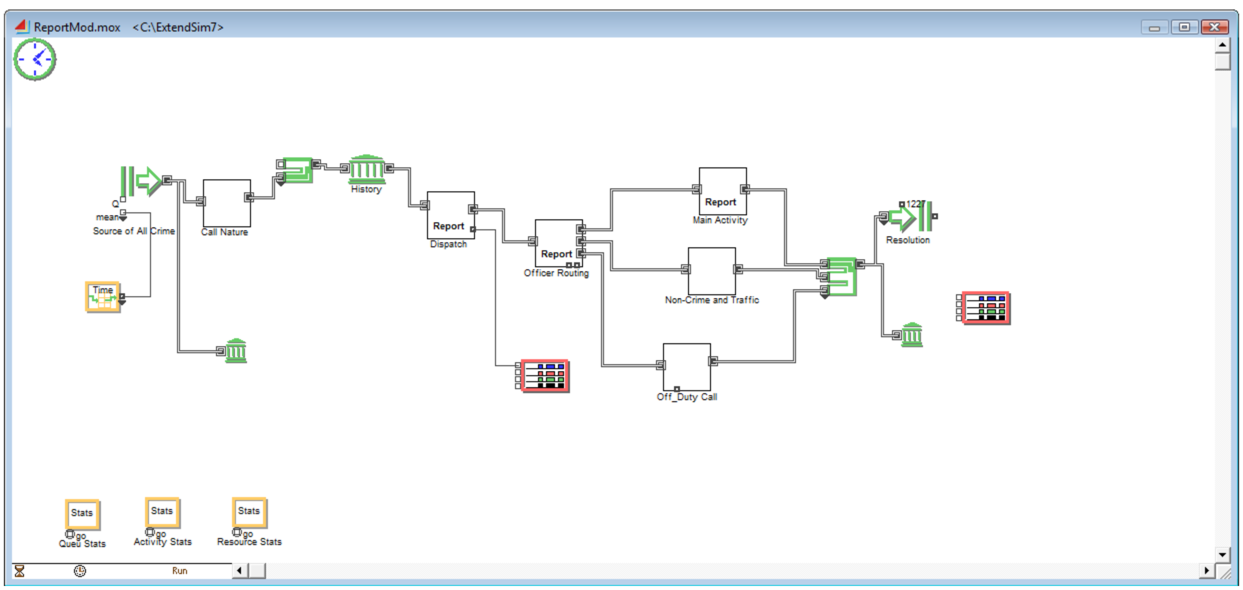


Figure 3 – Complete Simulation

The Creation of the Call Entity

The Call Entity arrives on an exponential distribution which varies depending on the time of day, and by the day of the week. The table uses six-hour blocks from 02:00-08:00, 08:00-14:00, 14:00-20:00, and 20:00-02:00 hours. These numbers were chosen because the arrangement ensured at least 30 samples in every block, and because upon testing, the final number of calls produced in a month was close to that of the historical data. The table below illustrates the arrival rates for February 2008, with the top 7 (25%) arrival rates highlighted in yellow.

Table 3: Arrival Rates

February Arrival Rates (Exponential Distribution, mean in minutes)

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
02 thru 8	22.11	45.78	49.25	39.3	29.89	32.88	30.73
8 thru 14	17.09	11.24	12.17	13.37	11.81	13.31	15.74
14 thru 20	18.1	11.95	10.65	12.36	12.84	12.52	14.51
20 thru 02	11.98	29.71	22.88	20.61	16.45	9.835	8.7

Interpreting this table, we see that peak hours are 20:00 Saturday to 02:00 Sunday, with an inter-arrival rate of only 8.7 minutes on average ($\lambda = .1149$). This is not surprising, as Saturday night is when many SLO residents are out drinking and partying, with no work or school the next day. Conversely, during the 02:00 through 08:00 Tuesday hours, we see an inter-arrival rate of 49.25 minutes, almost an hour ($\lambda = .0203$). This also makes *prima facie* sense, as few people would even be awake at that time.

It would be most appropriate to have more officers and dispatchers on duty during peak hours, as highlighted in yellow above. A linear programming problem can be created to try to distribute Officer resources to best meet demand (Crabill, et al, 1975). The proposed schedule includes extra officers on duty during overlap shifts on Wednesday, Thursday, Friday, and Saturday nights from 7:00 to midnight. The schedule would probably meet demand better by focusing on the latter two nights, and on the

other highlighted times. This chart will be presented to the police as a means to develop another alternative schedule; as of this writing, their response is pending.

Assigning Attributes

Assigning attributes to the call begins by determining the Nature attribute of the crime. Call Nature is based on empirical distribution from historic data , reprinted below. The number to the right of each possible Nature is the percentage of historical crimes of that type, as provided by the SLOPD. Note that the names are those used by the Dispatchers.

Table 4 - Crime Type Percentages

911_ABAN	2.78
ABAN_Vehi	2.83
DispatchAdvisory	0.43
Alarm_Audi	5.41
Alarm_Fire	0.82
Alarm_Silent	0.33
Alarm_Water	0.19
Alcohol_Off	3.76
Animal_Pro	0.95
Arson	0.01
Assault	1.07
Assist_O_F	0.22
Asisst_O_P	0.92
Assist_Req	1.93
Attempt_TH	0.1
Attempt_Lo	0.35
BOL	2.15
Bomb_Threat	0.01
Burg_Com	0.3
Burg_Res	0.62
Burg_Vehi	0.95
Child_Abuse	0.38
Citizen_Di	0.6
Coll_Freeway	0.04
Coll_Hit_A	1.37

False_Info	0.02
Fire_Electric	0.01
Fire_Unknown	0.03
Water_Inside	0.01
Fire_Vehicle_Frwy	0.01
Fire_Illegal	0.11
Fire_Threat	0.01
Fire_Out	0.06
Fire_Nonthreat	0.09
Fire_Structure	0.11
Fire_Alarm_Tamper	0
Fire_Vehicle	0.08
Fire_Wild	0.08
Fireworks	0.28
Forgery	0.04
Found_Prop	1.47
Fraud	1.11
Gas_Inside	0.04
Gas_Outside	0.07
Graffiti	0.61
Hazmat_Threat	0.01
Hazmat_Nonthreat	0.1
Emerg_Progress	0.1
Information	0.23
Juevnile_P	0.77

Mutual_Aid_Fire	0.01
Noise_Enhance	0.72
NOISE_2nd	0.35
Noise_other	0.84
Noise_Party	6.98
Noise_Poli	1.4
Parking_Pr	2.34
Posting_Camps	0.01
Posting_Ve	1.27
Probation	0.15
Prop_Dmg	0.02
Prowler	0.31
Public_Ass	0.81
Public_Wor	0.73
Recovered	0.02
Resisting	0.06
Robbery	0.1
Search_Warrant	0.02
Sex_Offense	0.3
Smoke_Check_In	0.11
Smoke_Check_out	0.13
Suicide_Att	0.16
Suspicious	5.65
Test	0.18
Theft	3.89

Coll_Major	0.05
Coll_Minor	0.73
Coll_Non_I	2.77
Communication	0.38
Controlled	0.75
Custodial Interference	0.04
Deceased	0.02
Disorderly	4.35
Domesitic_V	0.25
DUI	2.03
Electrical	0.22
Embezzlement	0.05

Keep_the_Peace	0.16
Kidnapping	0.02
Leaking_Hy	0.02
Littering_N/A	0.1
Loitering	0.17
Lost_Prop	0.81
Medical_Emerg	8.39
Medical_Nonemerg	0.01
MENTAL	0.48
Misc.	0.15
Missing_Per	0.44
MUNI_CODE	0.72

Theft_Vehi	0.26
Threatening	0.66
Tobacco	0.01
Towed_Vehi	4.13
Traffic_Ha	1.96
Traffic_Of	2.04
Trespassing	2.3
Vandalism	2.04
Warrant	0.62
Weapon_Off	0.24
CTW	2.03

For instance, in February 2008, 2.78% of all calls were 911-ABAN calls. Therefore, each call has a 2.78% chance of being assigned the 911-ABAN Call Nature Attribute (SLOPD 2010). This will later affect the call's Priority, how many officers must be dispatched, how long it takes to dispatch an officer, and how long it takes an officer to resolve the situation. All of this data is from a combination of established police procedure and historical data.

The screenshot below is the Call Nature Hierarchal Block. It assigns a random Nature, assigns attributes based on the Nature, and sends most values on to Dispatch. Under the newest model as of this writing, Traffic violations have a chance (currently 90%) to be sent directly to Traffic Officers, bypassing Dispatch and Travel Time altogether. This occurs only when Traffic Officers are available; at night, for example, they are not typically on duty, so regular Officer resources are assigned to the crime instead.

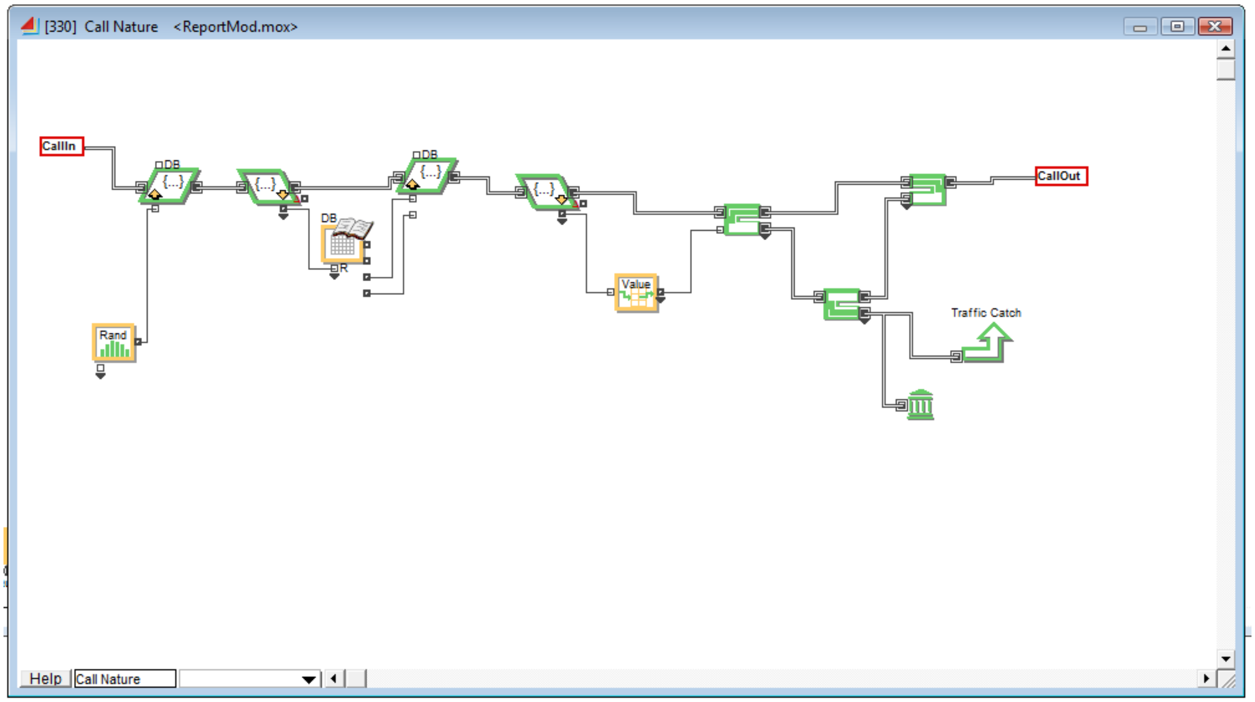


Figure 4 - Attributes Hierarchal Block

In actual operation, the department has some flexibility in assigning responses; calls will not always precisely follow procedure. For instance, an "Assault" crime may be a near-fatal stabbing, or simply one kid punching another in the mouth (SLOPD 2010). It would not make sense for the police to send six officers to respond to the latter case. For this reason, the Officers Required attribute is based off of historical data, rather than strict procedure, in order to more accurately reflect actual operation. A certain element of randomization is involved. Attributes are extensively detailed in their own section, and all tables are in the Appendix.

Call Waiting

In the Call Waiting Queue, calls wait for the next available Dispatcher. Calls are *not* yet sorted by priority – during actual operation, dispatchers have no way of knowing a call's nature until they talk

to the caller. This queue is also where preempted calls are sent when "put on hold". This queue does not assign any resources or attributes, and its capacity is treated as infinite.

During the Riot scenario, large numbers of calls can pile up very quickly. Unlike normal operations, in a riot, most crimes are likely to occur in the same general area. For this reason, during the Riot scenario, the Call Waiting Queue goes into Riot Mode when the queue exceeds six – a situation which has not occurred in any simulation under normal call rates, and which the department confirms is extremely unlikely. In Riot Mode, the Call Waiting Queue sends calls directly to Officer Resource Assignment, as it is assumed officers are now arriving at the scene of the major incident and are responding to what they see. Meanwhile, Dispatch continues to handle calls as they come in, and can continue to assign officers to tasks during the riot. This sort of decision-making and strategic changes were first modeled after reviewing SLOPD dispatch procedures.

Dispatch

The Dispatch Activity processes calls after they arrive from the Call Waiting Queue. In typical operation, dispatch consists of two or three dispatchers who receive 911 calls and radio communications from officers. Dispatch sometimes has a fourth operator on duty during holidays. To reflect this, the Activity block can process a number of simultaneous calls equal to the number of dispatchers on duty, according to the schedule.

The Dispatch Hierarchal Block is pictured below, including the aforementioned Call Waiting Queue.

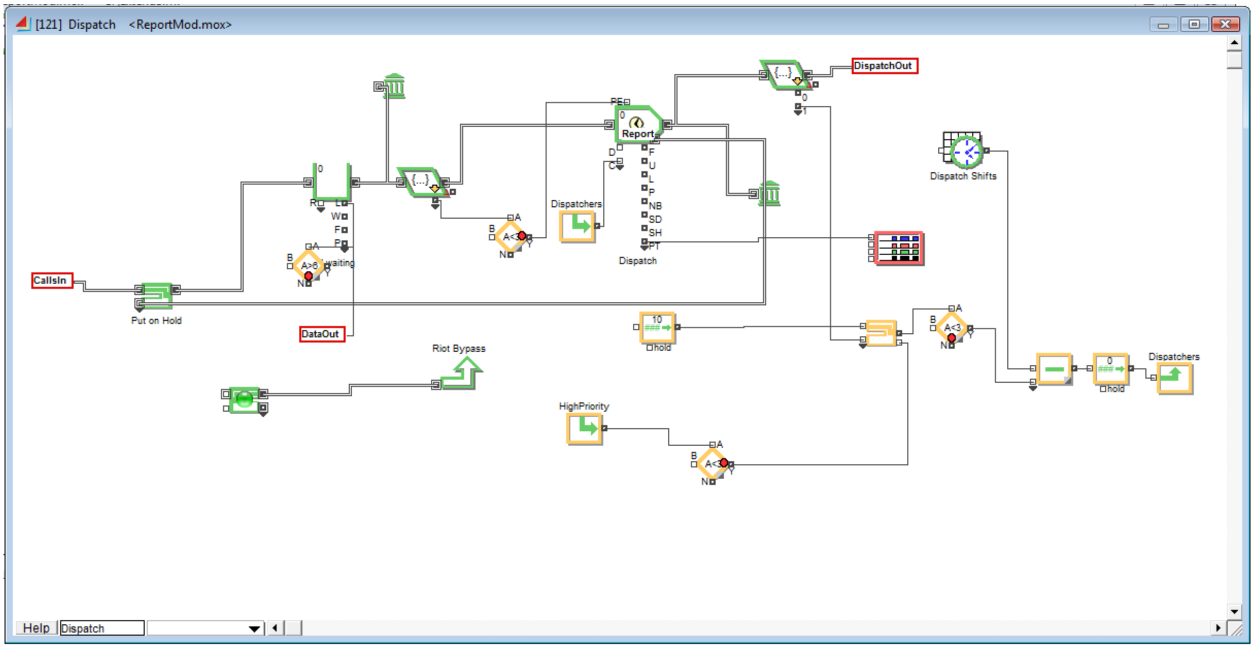


Figure 5 - Dispatch and Call Waiting

In addition to taking calls and assigning officers to tasks, dispatch also responds to certain types of calls directly. The most pertinent to the project is that, for certain calls, dispatchers remain on the line with the caller *after* assigning an officer to the location. For instance, according to procedure, when a Reporting Person calls about a prowler in their home, the dispatcher is instructed to keep the caller on the line until an officer arrives. To represent this, high-priority calls can "tie up" a single dispatcher, prevent one from taking further calls until it receives the signal that an officer is on the scene.

Processing time follows a lognormal distribution. Full lists of processing time can be found in the Appendix, although the raw data has been omitted since it is several thousand lines long.. Some manipulation of the data was required – the raw data included several instances where dispatch stayed on the phone with a caller, as mentioned previously. To reflect this, the process time was brought down to a lower, more realistic estimate, and the longer processing time is simply treated as the dispatcher being tied up, as detailed above. For low-priority calls, no manipulation was necessary.

Here is a sample distribution fitting, using a three-parameter lognormal distribution.

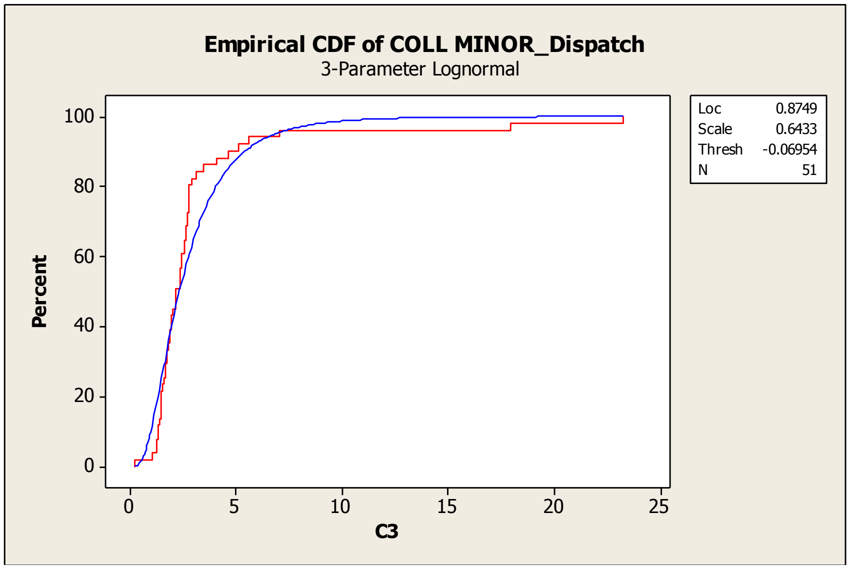


Figure 6 - Minor Collision Dispatch Distribution

In the raw data, dispatch typically spent only two to five minutes on this type of call; however, there were several incidents with calls taking twenty or thirty minutes. According to the dispatchers, this happens sometimes when callers refuse to get off the line. The final simulation will reflect this.

Fortunately, most of the data fits a lognormal distribution quite well. Because of the way ExtendSim designed their activity blocks, all crimes must use the same type of distribution, even if their parameters can be different. A few crimes, such as bomb threats, had too few sample data points to make a clean fit. Most of these low-frequency crimes are also high-priority, so the dispatch time is already approximated to a low number, followed by tying up the dispatcher resource until the officers are on-scene.

Assignment of Officer Resources

When a call has completed its time in the Dispatch Activity, it must then be assigned a certain number of Officer Resources. The number of officers assigned is determined by the Cops Required

Attribute. These officers are drawn from the Officer Resource pool, which has a number of available resources depending on the schedule. These resources remain tied to the Call Entity as it is later processed by the Travel Time, On Scene, and Report Activity blocks. After the On Scene activity is completed, the Officer resource is released back to the pool for further use.

Below is a screenshot of the Officer Assignment block.

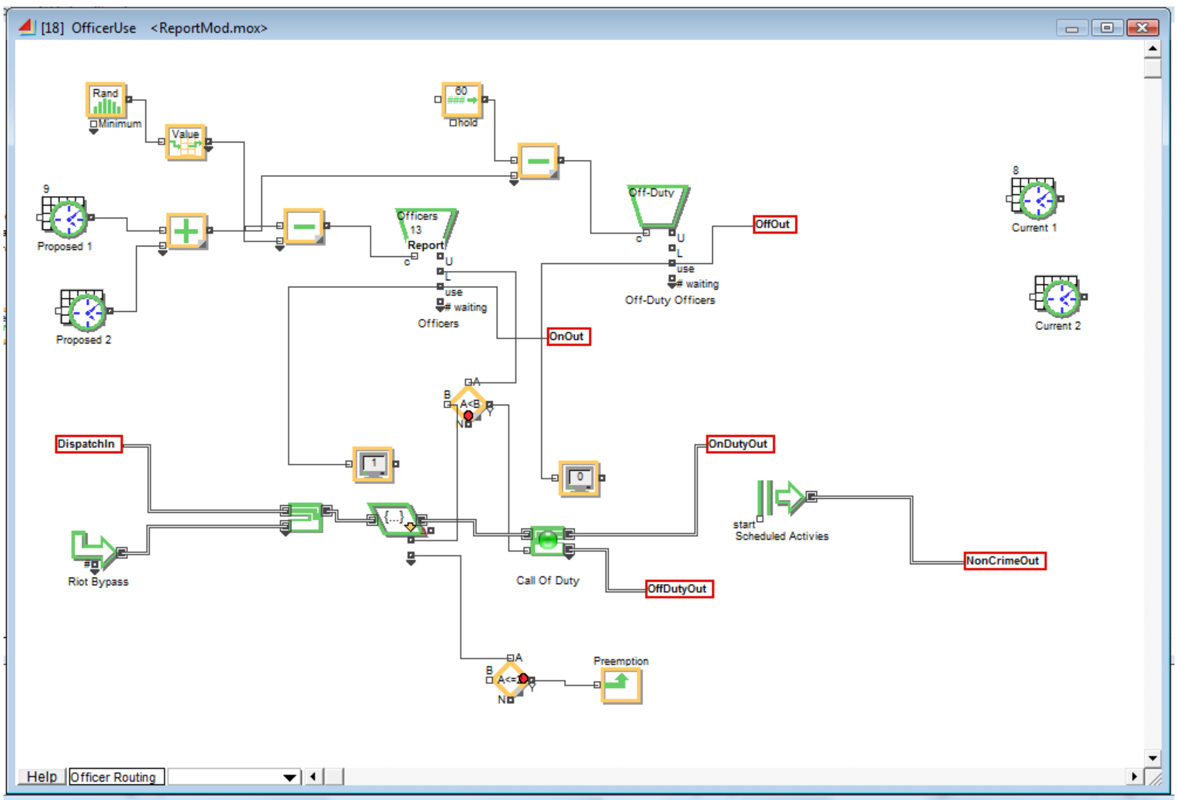


Figure 7 - Officer Assignment

In order to meet the requirements of the department, the simulation used two or more Shift Blocks to determine the number of officers available. This allows the operator to simulate the desired overlapping shifts. Additionally, a feature exists that randomly prevents one or more officers from showing up for their shift in order to reflect illness and injury. As of this writing, SLOPD is trying to determine their best estimate for this random chance. Until that time, the feature is either disabled, or, where noted, uses a 10% change of one absence and a 5% change of two absences.

McGee 2010

One version of the proposed schedule is displayed below.

Table 5- Proposed Schedule

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Day	6	6	6	6	6	6	5
Traffic	3	3	3	3	3	3	3
Night	6	6	6	6	6	6	6
Downtown	0	0	3	3	4	4	0
Cover	0	0	5	5	5	5	0

The Cover Shift under the proposed schedule is planned overtime, which officers sign up for ahead of time. Senior officers get the first pick.

The current schedule is displayed below. Note that there is no "cover" shift; officers still sign up for overtime during regular shifts.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Day	4	4	5	5	5	5	3
Traffic	1	1	1	1	1	1	1
Night	6	6	6	6	6	6	4
Downtown	0	0	2	2	2	2	1

Table 6 - Current Schedule

One of the primary goals of the simulation is to ensure that the number of officers available at any time is enough to match the demands of that shift. Below is a graph showing sixty hours of the simulation, starting at 0:00:00 Sunday and ending at 12:00:00 Tuesday. The blue line represents the number of officers currently assigned to a task at a given time. This plot comes straight from ExtendSim, which unfortunately does not have a very good plotting function, using the proposed schedule.

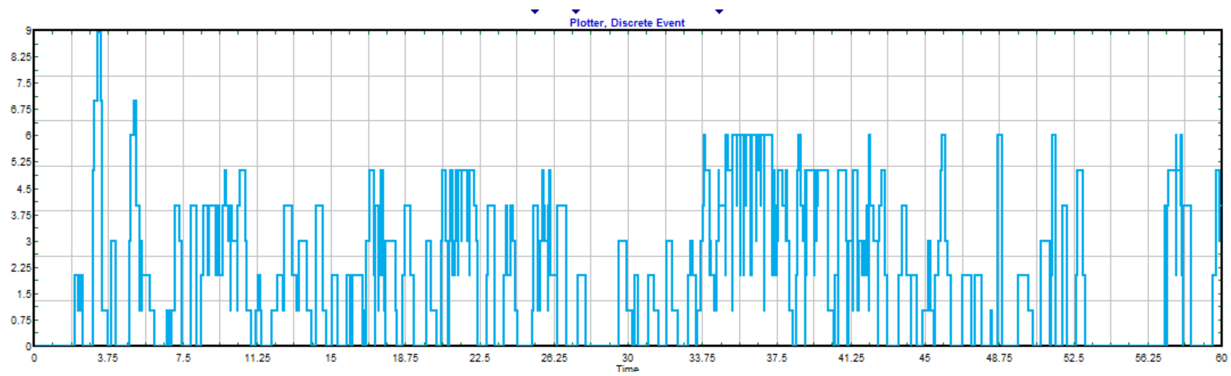


Figure 8 - Officer Utilization

The simulation gave an officer utilization rate of 35.01% for this sample time. Officers under the new schedule therefore have a lower utilization rate than the target number.

Three additional, optional resource types exist. The first, Off-Duty Officers, allows the operator to simulate calling officers to duty during their days off. This resource is *only* utilized in response to a shortage of available officers for high-priority calls (the default setting is priority 1, 2, or 3). Off-duty officers called into service remain on duty until the current shift ends. This resource is rarely utilized even once per shift under normal circumstances, and sees higher utilization only during the Riot Scenario.

The second optional resource is Out-of-Town Officers. These represent officers called in during major disasters to reinforce the local police, including California Highway Patrol, Cal Poly Police, and officers from other towns such as Pismo Beach. They only see use during the riot scenario, as the simulation does not even utilize this resource until all Off Duty Officers have been utilized. The simulation then reports how many Out-of-Town Officers were required, but that number does not represent useful data. This is because, in an actual emergency, SLOPD will not call other precincts and ask for the exact number of officers necessary to resolve a single call – they will ask for as many officers as are available. Instead, the use of even a single Out-of-Town Officer represents the occurrence of a major disaster, with the number required serving only as a general barometer of the severity.

During the interim presentation in late April 2010, the department decided they did not need data for Off-Duty or Out-of-Town officers. They instead expressed interest in a separate Traffic Officer Resource, which differs from other officer types in that they ride motorcycles, so they cannot be used for prisoner transport. While Traffic Officers can be sent to respond to crimes, there must always be at least one ordinary Officer Resource in order to successfully perform an arrest. Additionally, Traffic Officers often respond to traffic violations without being assigned by dispatch, so only the At Scene time distribution matters in these cases.

Travel Time

Travel Time is the time it takes an officer to get to the scene of a crime after being dispatched. There is insufficient historical data to determine if it is significantly affected by the number of officers on duty at once. It is unaffected by the Nature of a call. Travel time fits a lognormal distribution with the parameters of Mean = 4.4767 minutes, Standard Deviation = 2.1814 minutes, Location = 0.3819 minutes.

At Scene Activity

Once officers arrive on the scene, they spend an amount of time resolving the issue which is dependent on the nature of the call. Occasionally, while at the scene of a low-priority crime, officers may be subject to Preemption – that is, they may be required to leave the scene and respond to a higher-priority incident elsewhere. Officers typically return to the low-priority call later to complete its resolution.

Additionally, officers often have to write reports after a crime, which effectively removes them from the pool of available officers until they are finished. As of this writing, the department has not yet

estimated how often officers have to write immediate reports, or how long it takes to write one. Until that data becomes available, the simulation assumes the officers must file immediate reports 25% of the time, and that the report takes 15 minutes to fill out (significantly less than *this* report).

A screenshot of the Travel and At Scene Hierarchal Block is below.

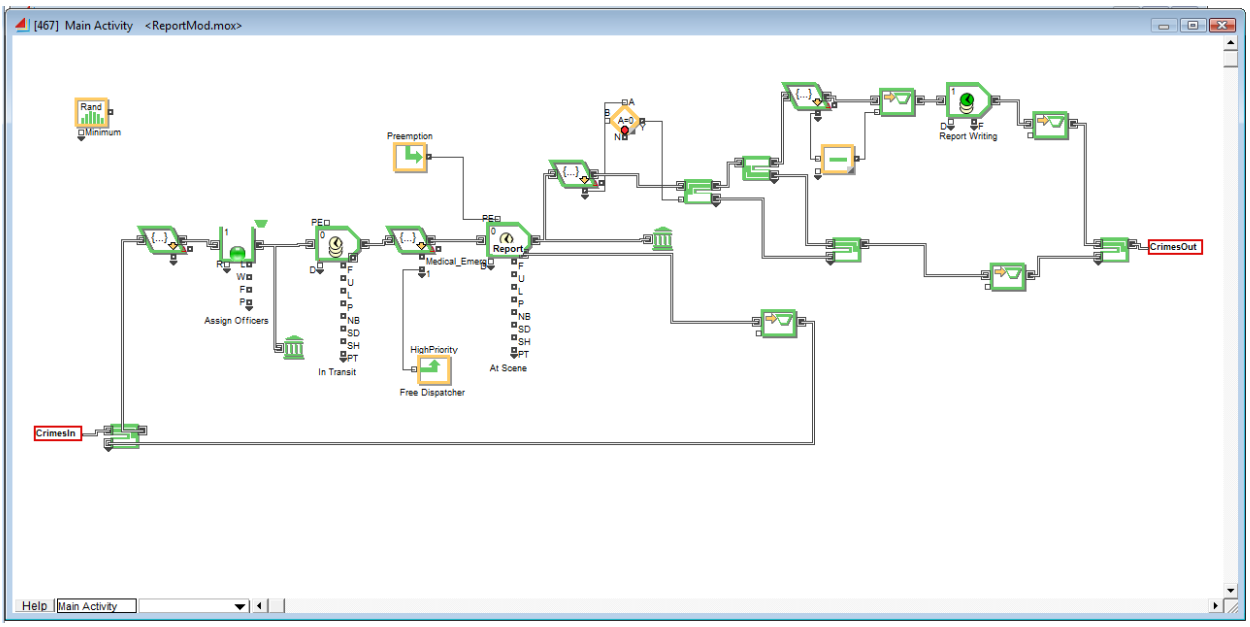


Figure 9 - Travel and At-Scene Block

Calls pass through the Assign Officer queue into the In Transit Activity Block, then pass to the At Scene Activity Block. If a dispatcher was on hold, this is when the simulation releases the dispatcher resource.

As mentioned previously, the At Scene Activity takes an amount of time which varies by Nature. This duration fits a lognormal distribution, with complete tables in the appendix. A sample appears below. All data is in minutes.

Table 7 - At Scene Distribution Sample

Nature	Average	Sigma	Location
911_ABAN	6.447548622	2.145537277	0.367144418

ABAN_Vehi	2.006777095	11.44553846	1
DispatchAdvisory	2.718281828	2.718281828	1
Alarm_Audi	7.849893776	2.370616386	0.302129363
Alarm_Fire	8.825983135	2.52212046	0.184704136
Alarm_Silent	22.02768343	1.182830151	0
Alarm_Water	13.47720851	0.409167775	1
Alcohol_Off	13.66038448	2.306451047	0.117009518
Animal_Pro	10.21850201	3.639695412	0.74230134
Arson	7.389056099	1	1
Assault	29.84149874	2.13834037	0.006749411
Assist_O_F	14.9887512	2.415702174	0.064544524
Asisst_O_P	14.9887512	2.415702174	0.064544524
Assist_Req	14.18946801	2.608042657	0.164014572
Attempt_TH	47.04478404	1.235838887	3.60E-15
Attempt_Lo	12.29877913	3.630970616	0.867274277
BOL	0.1	0	0

Some numbers have had to be modified in order to function correctly in ExtendSim, but the department confirms that the simulation is outputting realistic numbers. For example, “BOL” is the Dispatch code for “Be on the lookout,” a type of call where dispatch informs every officer on duty to watch for individuals fitting a certain description. There is no significant response time associated with this call type; officers simply confirm receipt of the order. As such, the raw data does not include any numbers for response time. ExtendSim does not accept a lognormal average of zero, so .1 minutes was substituted.

Upon completion of the activity, Officer Resources are released back into the system for further use. If the crime requires a report, all but one Officer will be released; that Officer Resource is released upon completion of the report.

Resolution & Data Gathering

Once the crime has been responded to in full, all officers are released back to the system, and the Call Entity is recorded before being removed completely from the system. All these events are recorded, then the final data from each run is exported to an Excel file for statistical analysis.

In a typical trial, the simulation will repeat for 50 runs of 720 hours (30 days) using the February 2008 crimes rates. All results will be from these conditions unless explicitly stated otherwise.

Methodology: Analyzing the Output

All results from the simulation are exported to Excel for analysis. This required the design of a unique spreadsheet, which is very sensitive to changes in the simulation. Since even slight changes to the simulation will change the location of outputs to the spreadsheet, it was necessary to design a Visual Basic program to re-create spreadsheets macros on demand. Depending on the demand, the file can display different sorts of statistical information. Here is a sample output from a portion of the Excel sheet:

Table 8 - Sample Final Output

X	**Average Time in Queue (Minutes)**			**St. Dev.**
Call Waiting	0.05	+ or -	0.03	0.01
Assign Officers	0.02	+ or -	0.01	0.01
Total	0.07	+ or -	0.96	0.48

X	**Number of Calls**			**St. Dev.**
# of Incidents	2479.66	+ or -	107.43	53.72

X	**Maximum Number of Activities**			**Std. Dev**
Dispatch	2.98	+ or -	0.28	0.1414
On-Scene	4.96	+ or -	0.57	0.2828
In Transit	4.22	+ or -	0.929340341	0.4647
Traffic Stop	1.82	+ or -	1.05	0.5226
Report Writing	3.16	+ or -	0.84	0.4219

The "+ or -" indicates a two standard deviation interval. This format is retained because it is easy to present in layman's terms to the clients at SLOPD.

For the report to SLOPD, two or more schedules will be compared, and the data will be stored for comparison. They have expressed interest primarily in the average response times, average number

of simultaneous activities (crimes, calls, and reports), and the utilization rate for dispatchers and officers. As of this writing, the department has not yet sent in its current schedule, or its "final proposed" schedule, so any data will be based on the author's own informally-gathered notes. Final numbers should be in before the final report is due.

Outputs are analyzed and graphed in Minitab. Because of the Central Limit Theorem, the averages of all sample results can be graphed as normal curves and compared using standard Hypothesis Testing. That is, the sum of the Call Waiting time (q_c) plus the time in the dispatch activity (a_d, a lognormal distribution of time) plus the time spent waiting for an available officer (q_o) plus the travel time of the officer (a_t, a lognormal distribution of time) is defined as the response time (*rt*).

$$rt \stackrel{\text{def}}{=} q_c + a_d + q + a_{tc}$$

The response time is expressed as a normal curve using the sample data from 50 trials, so each variable in fact represents the average of 720 hours worth of simulated operation (represented by using capital letters). The real mean would therefore be the sum of average values from all fifty trials.

$$RT_{avg} = \sum_{i=1}^{50} Q_{ci} + A_{di} + Q_{oi} + A_{tci}$$

The standard deviation would therefore be as follows:

$$RT_{stdev} = \sqrt{\frac{1}{50}\sum_{i=1}^{50}(RT_{avg\ i} - \overline{RT_{avg}})}$$

Given these values, we perform a test of hypothesis (Wilcox 2001). The null hypothesis will be that the new schedule results in a response time greater than or equal to that of the current schedule,

while the alternative is that the new schedule results in a lower response time. For this test, $\alpha = 0.05$, H_0: $RT_{new} \le RT_{current}$, and H_A: $RT_{new} > RT_{current}$.

Here is a sample comparison of response times under the current and proposed plans, without the use of a special Traffic Officer resource. This graph uses older data to better illustrate the goal; more current data is in the results section.

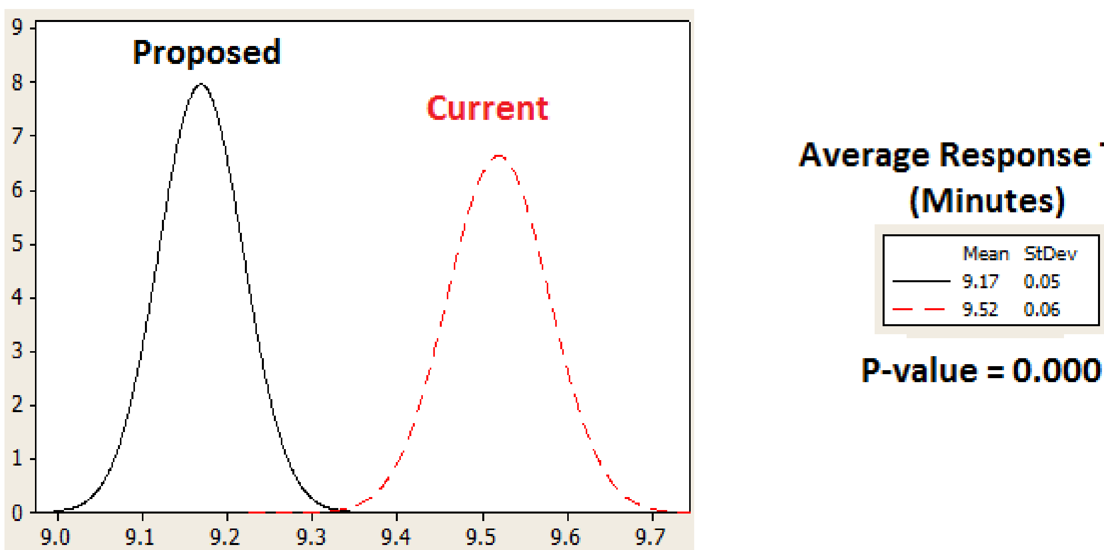


Figure 10 - Sample Response Time Comparison

This sample shows a reduction of response time of about twenty seconds (0.35 minute). The difference is statistically significant, with a P-value of 0.000. With a standard deviation of 0.06, and the given Null and Alternative hypotheses, we can detect a difference of 0.0279141 minute (1.675 second) with a Power of 0.95. While this is certainly statistically significant, whether it is practically significant will be up to the client.

After the above analysis was presented at the interim meeting with SLOPD, several changes were requested. First, the department had decided to focus on whether or not a schedule was

adequate, rather than on cost, so no further cost-tracking features were developed. They also released the new and proposed schedules, and asked for a comparison. The new schedule included a separate type of officer, Traffic Officers, who could respond to any call, but could not perform arrests because they are on motorcycles. This means that all crimes except traffic stops must have at least one regular officer assigned to them. Additionally, traffic officers mostly operate during the day, so regular officers have to be able to take over traffic calls at night.

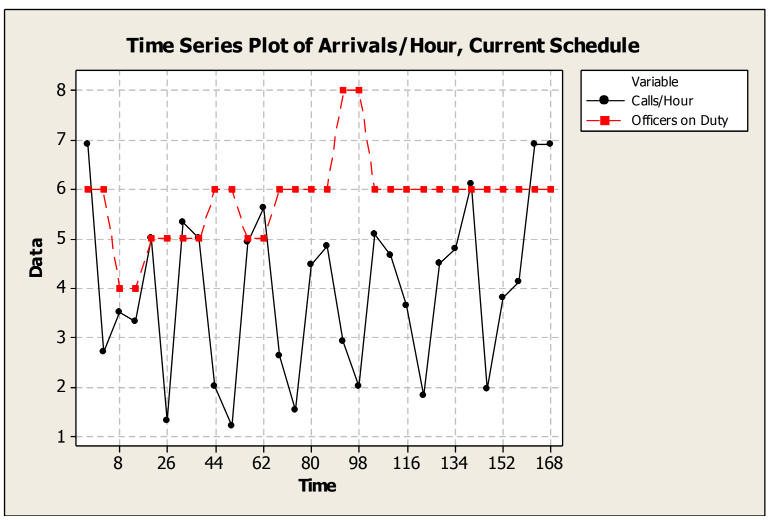
Other analyzed data includes average and maximum queue lengths, officer utilization, and maximum number of concurrent activities.

Methodology: Graphical Analysis

In addition to simulation, it is possible to use linear analysis to examine the current and proposed schedules (Crabill et al, 1975). The graphical representation of call arrival rates versus officer availability is much easier to present to the police than just numbers, or simulation results.

First, to find the average calls/hour, divide 60 by the arrival rate in minutes (See Table 3). Plot the average calls/hour on the same chart as the number of officers on duty by time, over one week. Examine using a graphical approach, which will be presented to the police.

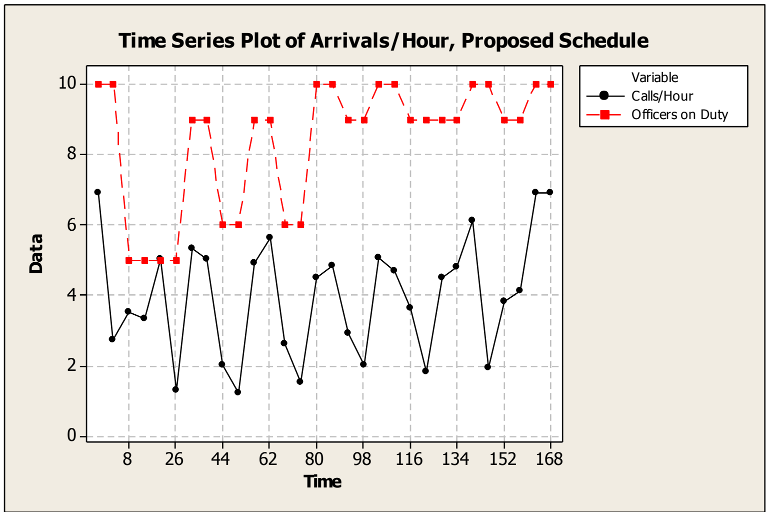
The intention of these graphs is *not* for the number of officers to precisely match the number of calls. Some calls require more than one officer, and it is desirable to have at least one officer free at all times. Additionally, sometimes a shift is under-manned because an officer is sick or injured. Visually speaking, the goal is for the peaks and valleys of the incoming call rate to run close to parallel to those of the officers on duty.



The current schedule under-covers during the Saturday Night, Sunday Night and Monday Day shifts, and over-covers during the Thursday Day Shift. While the simulation showed that the current

number of officers is acceptable on average, this schedule does not allow much slack at the under-covered times.

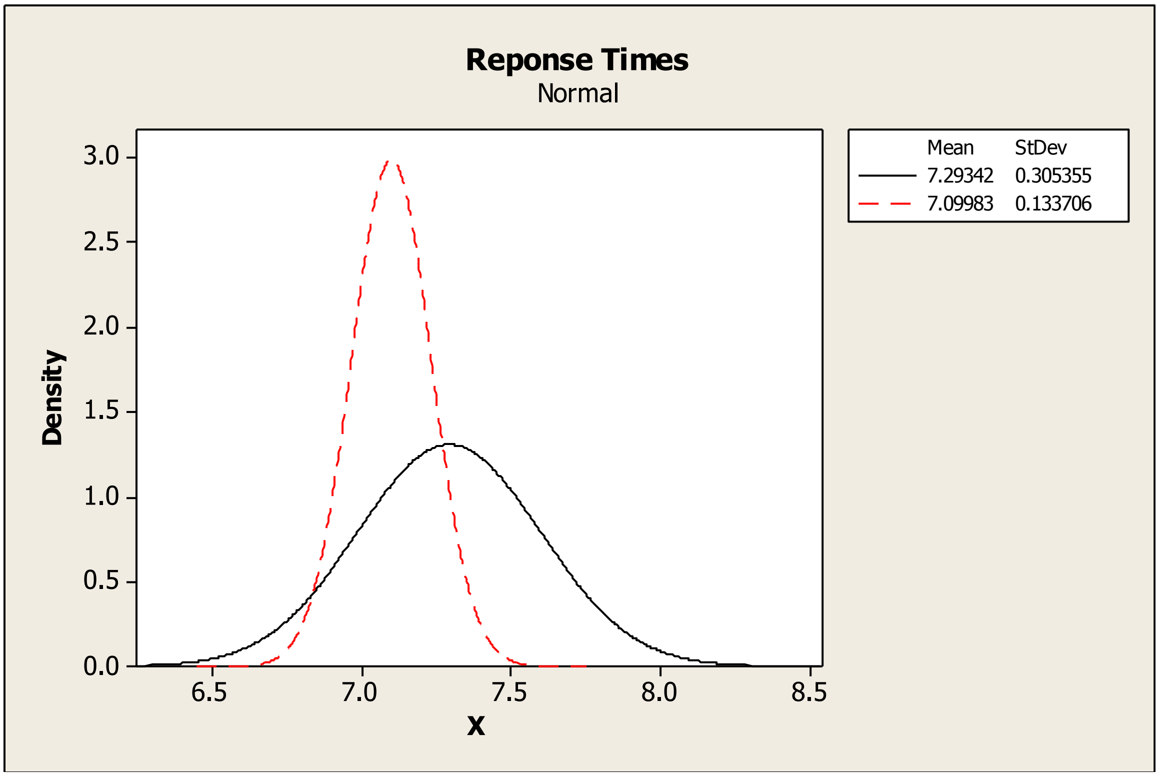
Compare the proposed schedule below.



Except for the Sunday Day shift, this schedule much more closely follows the curve of the arrival rate. It is debatable whether it over-covers on Wednesday through Friday night. This shift uses more officers than the previous one; if the police intend to field that many officers, then this schedule is a reasonable use of them.

Results

The final comparison of schedules produced this result:



In this trial, note that overall response times appear to be significantly faster for both schedules. This is because the traffic officers represent the addition of more officers to the schedules, both current and proposed, so more officers are available at all times. Comparing the two, the difference is a much smaller 0.2 minute (12 seconds), which is not practically significant. The inclusion of the traffic officers seems to have closed the gap in total response time. However, there are typically no specialized Traffic Officers on motorcycles at night, so the proposed night schedule must be an improvement, or else the variance would be greater.

However, the standard deviation is much smaller, which means police response is much more reliable. Three standard deviations above the mean in the proposed schedule is still only 7.5 minutes;

three standard deviations above the mean in the current schedule is 8.2 minutes. This is a difference of .7 minute (42 seconds), which is practically significant.

The reason for the small difference is because of the following stats:

Current Schedule	**Average Time in Queue (Minutes)**			**St. Dev.**
Call Waiting	0.09	+ or -	0.04	0.02
Assign Officers	0.21	+ or -	0.13	0.07
Total	0.30	+ or -	0.28	0.14

Proposed Schedule	**Average Time in Queue (Minutes)**			**St. Dev.**
Call Waiting	0.06	+ or -	0.02	0.01
Assign Officers	0.05	+ or -	0.03	0.01
Total	0.11	+ or -	0.07	0.03

As mentioned previously, travel time and dispatch time do not vary much. Call Waiting and Officer Assignment are the primary sources of disparity in scheduled response time. The current schedule's average total of those two values is only 0.3 minute, or about 20 seconds. There is not much improvement that can be done on this number – in fact, it is an indication that the current schedule appears to be adequate, at least as far as average response time goes.

Other useful metrics include the maximum number of simultaneous activities, average queue lengths, and officer utilization. The maximum response times and maximum queue times are not useful data, because the standard deviation is typically almost equal to the mean. This is because very low-priority crimes, such as abandoned vehicles, may be repeatedly preempted or left without an assigned officer in favor of a higher-priority call in the Assignment queue.

Compare the maximum number of activities below between the current and proposed schedules, which is a number determined by the number of available officers. Under the proposed

schedule, more officers will generally be available at any given time; naturally, it follows that the department can handle more concurrent activities.

Current Schedule	Maximum Number of Activities			Std. Dev
Dispatch	2.00	+ or -	0.00	0
On-Scene	3.94	+ or -	0.48	0.2399
In Transit	3.5	+ or -	1.010152545	0.50508
Traffic Stop	1.00	+ or -	0.00	0
Report Writing	2.96	+ or -	0.80	0.40204

Proposed Schedule	Maximum Number of Activities			Std. Dev
Dispatch	2.98	+ or -	0.28	0.1414
On-Scene	5.1	+ or -	0.93	0.4629
In Transit	4.32	+ or -	1.102131516	0.5511
Traffic Stop	1.56	+ or -	1.08	0.5406
Report Writing	3.26	+ or -	0.89	0.4431

Table 9 - Maximum Number of Activities

Under the proposed schedule, the police can respond to more simultaneous calls. This reduces their maximum response time during peak hours, but it also increases the peak workload of the dispatchers.

Results: Presentation

The interim presentation to SLOPD occurred on April 28th, 2010. It was a two-hour explanation of the project, including a live demonstration. The police were invited to comment on any assumptions made by the simulation and propose suggestions to any errors, as well as input different schedules on the spot for immediate testing. Several false assumptions were dispelled, such as the policy for use of off-duty officers. Additionally, several changes were made to the deliverables. The police were no longer interested in a Riot scenario or in typical operating costs; rather, they wanted officer utilization rates, report-writing times, and a breakdown of officers into Traffic and non-Traffic Officers.

Officer utilization is the amount of time officers are engaged in a specific task, either in-transit, at a scene, or writing a report. The department target is 65-70% (SLOPD 2010). For report-writing, SLOPD has indicated that officers are required to write an immediate report of incidents approximately 28% of the time, and that a report takes about fifteen minutes to complete. The report-writing activity was added to the simulation after this meeting.

Traffic Officers are defined as those officers who cannot perform arrests due to their use of motorcycles. Despite the name, Traffic Officers do respond to all types of calls, so the simulation needed to be modified to include a mix of Traffic and non-Traffic Officer resources for every Call entity. For any crime in which arrest was a possibility, at least one non-Traffic Officer resource had to be assigned to the Call entity.

As of this writing, the final presentation to the police department has not yet taken place. It should happen within the next several weeks, depending on the schedules of project. All proposed changes to the simulation have been met, though officer utilization tests at 25-40% under the current system, depending on the schedule. The author is determining now if this is a result of a flaw in the

simulation, or a realistic result indicating under-utilization of existing resources. Still, as indicated earlier in Results, the proposed schedule consistently tests as more reliable and flexible for the department, and appears to be the best recommendation.

Conclusion

On a short-term level, this simulation study is a success. The SLOPD daily operations have been modeled, and the schedules tested. It appears that the current schedule is adequate to current needs, but that the newer proposed schedule would improve a number of metrics : reducing the variance of response time, reducing the time spent in queues, and increasing the maximum number of simultaneous activities. If the officers are available for the schedule, we will recommend they implement it.

Long-term, the project is readily adaptable to other departments. The author can take raw data from Spillman software, transfer it to Excel and Minitab, then produce the necessary statistical data for typical modeling. Other metrics, such as the rate of officer illness or the fraction of crimes that require immediate report-writing, can be input directly into the simulation using anything from an off-the-cuff guess to an actual study.

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Appendix

		Nature	Mu	Sigma	Loc
911_ABAN	1	911_ABAN	1.3488	1.0253	0.50323
ABAN_Vehi	2	ABAN_Vehi	1.2644	0.64632	0
DispatchAdvisory			1	0	0
Alarm_Audi	3	Alarm_Audi	1.147	0.81756	0.09271
Alarm_Fire	4	Alarm_Fire	1.3912	0.30115	0
Alarm_Silent	5	Alarm_Silent	0.31593	0.72743	0.90901
Alarm_Water	6	Alarm_Water	1.2236	0.39531	1.7216
Alcohol_Off	7	Alcohol_Off	1.7232	1.1313	0
Animal_Pro	8	Animal_Pro	2.1335	1.6588	1.4162
Arson			10	0	0
Assault	9	Assault	1.5117	1.7811	1.118
Assist_O_F			1.3362	1.11685	0.93814
Asisst_O_P	10	Assist_O_P	1.3362	1.11685	0.93814
Assist_Req	11	Assist_Req	1.936	1.0555	0.37518
Attempt_TH	12	Attempt_TH	2.6481	1.3429	0
Attempt_Lo	13	Attempt_Lo	2.1455	2.7381	3.9964
BOL			1	0	0
Bomb_Threat	14	Bomb_Threat	10	0	0
Burg_Com	15	Burg_Com	2.3381	1.3383	0
Burg_Res	16	Burg_Res	2.3191	1.6878	0.53522
Burg_Vehi	17	Burg_Vehi	2.3983	1.2082	1.3833
Child_Abuse	18	Child_Abuse	10	0	0
Citizen_Di	19	Citizen_Di	1.1854	1.3099	2.7635
Coll_Freeway	20	Coll_Freeway	-0.01772	7.2922	2.9833
Coll_Hit_A	21	Coll_Hit_A	1.8933	1.168	0.74632
Coll_Major	22	Coll_Major	1.0152	0.89192	0
Coll_Minor	23	Coll_Minor	0.98224	0.67977	0.02818
Coll_Non_I	24	Coll_Non_I	1.4798	0.99715	0
Communication	25	Communication	2.4893	0.65968	0
Controlled	26	Controlled	1.7959	1.0335	0.46803
Custodial Interference			5	0	0
Deceased	27	Deceased	5	0	0
Disorderly	28	Disorderly	1.3469	0.91865	0
Domesitic_V	29	Domesitic_V	1.6818	1.6964	0.9337
DUI	30	DUI	1.0884	1.7872	0
Electrical	31	Electrical	1.0189	1.1339	1.0894
Embezzlement			15	0	0
False_Info			1	0	0

Fire_Electric	32	Fire	1.1549	0.99372	1.2623
Fire_Unknown			1.1549	0.99372	1.2623
Water_Inside			1.1549	0.99372	1.2623
Fire_Vehicle_Frwy			1.1549	0.99372	1.2623
Fire_Illegal			1.1549	0.99372	1.2623
Fire_Threat			1.1549	0.99372	1.2623
Fire_Out			1.1549	0.99372	1.2623
Fire_Nonthreat			1.1549	0.99372	1.2623
Fire_Structure			1.1549	0.99372	1.2623
Fire_Alarm_Tamper			1.1549	0.99372	1.2623
Fire_Vehicle			1.1549	0.99372	1.2623
Fire_Wild			1.1549	0.99372	1.2623
Fireworks	33	Fireworks	2.3452	1.2331	2.0475
Forgery	34	Forgery	5	0	0
Found_Prop	35	Found_Prop	2.6667	1.3263	0
Fraud	36	Fraud	2.336	1.2123	- 0.18753
Gas_Inside	37	Gas_Inside	2.1869	0.11683	-5.3069
Gas_Outside			2.1869	0.11683	-5.3069
Graffiti	38	Graffiti	0.92435	1.7541	4.0053
Hazmat_Threat	39	Hazmat	1.0627	0.94419	2.5038
Hazmat_Nonthreat			1.0627	0.94419	2.5038
Emerg_Progress			0.48145	1.9141	1.013
Information			15	0	0
Juevnile_P	40	Juevnile_P	1.6973	1.2571	0.64665
Keep_the_Peace	41	Keep_the_Peace	1.9108	0.61385	0
Kidnapping	42	Kidnapping	3	0	0
Leaking_Hy	43	Leaking_Hy	3.8115	0.03002	-40.888
Littering_N/A	44	Littering_N/A	5	0	0
Loitering	45	Loitering	1.6941	1.6616	2.0556
Lost_Prop	46	Lost_Prop	10	0	0
Medical_Emerg	47	Medical	0.84925	0.74655	0.63814
Medical_Nonemerg			0.84925	0.74655	0.63814
MENTAL	48	MENTAL	1.4514	1.1495	0.81978
Misc.	49	Misc.	15	0	0
Missing_Per	50	Missing_Per	3.1474	0.4909	5.8834
MUNI_CODE	51	MUNI_CODE	2.3207	0.86083	0
Mutual_Aid_Fire			1.1549	0.99372	1.2623
Noise_Enhance			1	0	0
NOISE_2nd	52	NOISE_2nd	2.5656	1.0657	0
Noise_other	53	Noise_other	1.8067	1.3812	1.5622
Noise_Party	54	Noise_Party	2.0117	1.325	0.5851
Noise_Poli	55	Noise_Poli	2.7772	1.1298	0

Parking_Pr	56	Parking_Pr	1.9103	1.3843	0.58228
Posting_Camps			2.517	1.9482	0.88135
Posting_Ve	57	Posting_Ve	2.517	1.9482	0.88135
Probation	58	Probation	30	0	0
Prop_Dmg			15	0	0
Prowler	59	Prowler	0.97536	0.34641	-0.35215
Public_Ass	60	Public_Ass	1.5231	0.68691	0
Public_Wor	61	Public_Wor	1.7382	0.90638	0
Recovered	62	Recovered	1	0	0
Resisting	63	Resisting	1	0	0
Robbery	64	Robbery	0.99005	0.87562	1.85
Search_Warrant			60	0	0
Sex_Offense	65	Sex_Offense	2.5699	1.8291	0
Smoke_Check_In	66	Smoke_Check	1.4834	0.65119	0
Smoke_Check_out			1.4834	0.65119	0
Suicide_Att	67	Suicide_Att	2.5272	6.0408	2.3167
Suspicious	68	Suspicious	1.7104	1.0528	0.6235
Test			1	0	0
Theft	69	Theft	2.3274	1.4878	0.80146
Theft_Vehi	70	Theft_Vehi	2.8214	1.4442	0
Threatening	71	Threatening	1.9484	1.2833	2.6089
Tobacco			1	0	0
Towed_Vehi	72	Towed_Vehi	1.1072	1.9407	0.19039
Traffic_Ha	73	Traffic_Ha	1.7216	1.2175	0.24458
Traffic_Of	74	Traffic_Of	1.8196	1.0862	0.16664
Trespassing	75	Trespassing	1.7178	1.3619	1.5293
Vandalism	76	Vandalism	2.1196	1.6127	0.26771
Warrant	77	Warrant	2.2783	1.0075	-1.0673
Weapon_Off	78	Weapon_Off	1.015	0.15573	0
CTW	79	Weflare_Ch	1.7563	1.042	1.073

Table 10 - Dispatch Time Parameters (Lognormal)

Index	Nature	Mu	Sigma	Location
1	911_ABAN	6.447548622	2.145537277	0.367144418
2	ABAN_Vehi	2.006777095	11.44553846	1
3	DispatchAdvisory	2.718281828	2.718281828	1
4	Alarm_Audi	7.849893776	2.370616386	0.302129363
5	Alarm_Fire	8.825983135	2.52212046	0.184704136
6	Alarm_Silent	22.02768343	1.182830151	1.27E-07
7	Alarm_Water	13.47720851	0.409167775	1
8	Alcohol_Off	13.66038448	2.306451047	0.117009518
9	Animal_Pro	10.21850201	3.639695412	0.74230134
10	Arson	7.389056099	1	1

11	Assault	29.84149874	2.13834037	0.006749411
12	Assist_O_F	14.9887512	2.415702174	0.064544524
13	Asisst_O_P	14.9887512	2.415702174	0.064544524
14	Assist_Req	14.18946801	2.608042657	0.164014572
15	Attempt_TH	47.04478404	1.235838887	3.60E-15
16	Attempt_Lo	12.29877913	3.630970616	0.867274277
17	BOL	0.1	0	0
18	Bomb_Threat	2.718281828	1	1
19	Burg_Com	31.26189676	2.178529265	0.003344293
20	Burg_Res	41.47952782	2.115582102	0.003141987
21	Burg_Vehi	29.66595227	1.861904707	0.000857662
22	Child_Abuse	0.379310556	4.105386944	1
23	Citizen_Di	22.88541939	1.822938938	0.009769402
24	Coll_Freeway	4.956500761	13.08543788	1
25	Coll_Hit_A	19.48412439	2.514112856	0.102776351
26	Coll_Major	49.9139239	2.219251551	0.768511309
27	Coll_Minor	24.63332005	2.275978341	0.007422792
28	Coll_Non_I	21.46234491	2.228636581	0.034503311
29	Communication	10	1.065058791	1
30	Controlled	12.56732259	4.246096117	0.656849735
31	Custodial Interference	7.389056099	1	1
32	Deceased	20.08553692	1	1
33	Disorderly	12.33326397	2.452407021	0.195225496
34	Domesitic_V	18.23239579	3.293003282	0.403451095
35	DUI	18.43221594	2.845958734	0.149284709
36	Electrical	14.77298242	3.853570033	0.433137521
37	Embezzlement	10	1	1
38	False_Info	11.16741318	6.645899181	0.857700764
39	Fire_Electric	11.16741318	6.645899181	0.857700764
40	Fire_Unknown	11.16741318	6.645899181	0.857700764
41	Water_Inside	11.16741318	6.645899181	0.857700764
42	Fire_Vehicle_Frwy	11.16741318	6.645899181	0.857700764
43	Fire_Illegal	11.16741318	6.645899181	0.857700764
44	Fire_Threat	11.16741318	6.645899181	0.857700764
45	Fire_Out	11.16741318	6.645899181	0.857700764
46	Fire_Nonthreat	11.16741318	6.645899181	0.857700764
47	Fire_Structure	11.16741318	6.645899181	0.857700764
48	Fire_Alarm_Tamper	11.16741318	6.645899181	0.857700764
49	Fire_Vehicle	11.16741318	6.645899181	0.857700764
50	Fire_Wild	11.16741318	6.645899181	0.857700764
51	Fireworks	6.139848085	2.100236589	0.713052663
52	Forgery	2.718281828	1	1

53	Found_Prop	7.018152453	4.414082508	0.798436371
54	Fraud	10	2.434520945	0.071247183
55	Gas_Inside	7.842047806	6.17865123	1
56	Gas_Outside	7.842047806	6.17865123	1
57	Graffiti	4.860299201	2.436591167	0.488996474
58	Hazmat_Threat	6.962231216	6.722095928	0.928207474
59	Hazmat_Nonthreat	6.962231216	6.722095928	0.928207474
60	Emerg_Progress	39.20483182	1.481759155	1
61	Information	6.1829778	13.88626192	1
62	Juevnile_P	8.082490054	3.502580561	0.637628152
63	Keep_the_Peace	15.56305755	2.429851149	35.20893903
64	Kidnapping	2.718281828	1	1
65	Leaking_Hy	3.814081975	8.988985549	1
66	Littering_N/A	10	1	1
67	Loitering	16.59995526	1.392276253	0.000101485
68	Lost_Prop	0.574899521	5.522882964	1
69	Medical_Emerg	22.33153935	1.820242984	0.001978137
70	Medical_Nonemerg	22.33153935	1.820242984	0.001978137
71	MENTAL	22.64185082	2.188135913	0.082093208
72	Misc.	3.882968739	4.066163801	1
73	Missing_Per	15.88539288	2.673744702	0.140394354
74	MUNI_CODE	11.38389913	1.870208646	0.078097284
75	Mutual_Aid_Fire	11.16741318	6.645899181	0.857700764
76	Noise_Enhance	2.718281828	1	1
77	NOISE_2nd	13.29781851	1.887531706	0.024350571
78	Noise_other	7.033609384	1.996568586	4.974873783
79	Noise_Party	20.27725876	1.287059295	1
80	Noise_Poli	14.31774962	1.886890055	0.025714506
81	Parking_Pr	5.953028014	3.370631111	0.790096649
82	Posting_Camps	1.570493655	3.098753705	1
83	Posting_Ve	1.570493655	3.098753705	1
84	Probation	48.29847564	1.53245343	1
85	Prop_Dmg	2.718281828	1	1
86	Prowler	13.52581389	1.806118378	0.12640048
87	Public_Ass	10.58777464	2.166276944	0.38852413
88	Public_Wor	5.538922571	2.833747385	0.593273365
89	Recovered	20	1	1
90	Resisting	25	1	1
91	Robbery	35.75892899	2.40117932	1
92	Search_Warrant	2.718281828	1	1
93	Sex_Offense	43.82918852	2.233366303	0.000719323
94	Smoke_Check_In	4.880267334	9.770816161	1
95	Smoke_Check_out	4.880267334	9.770816161	1

96	Suicide_Att	22.19795128	4.764535258	1
97	Suspicious	10.7359723	2.811730134	0.395501777
98	Test	2.718281828	1	1
99	Theft	22.4547012	2.234818463	0.013557709
100	Theft_Vehi	57.35155744	1.523301471	1.65E-10
101	Threatening	28.25018482	1.910452261	0.000517397
102	Tobacco	2.718281828	1	1
103	Towed_Vehi	6.663201002	3.831667167	1
104	Traffic_Ha	5.395687374	3.347788572	0.820533944
105	Traffic_Of	11.35547493	2.676152156	0.309344418
106	Trespassing	13.82114962	2.166341933	0.075857401
107	Vandalism	13.97541899	2.410730949	0.117843241
108	Warrant	21.30624027	2.527169748	0.09495046
109	Weapon_Off	19.90358766	2.3975323	1
110	CTW	11.49715944	2.308827916	0.189342071

Table 11 - At-Scene Times

Cumulative Probability	Nature	Officers	Priority
2.78	911_ABAN	2	3
5.61	ABAN_Vehi	1	9
6.04	DispatchAdvisory	0	9
11.45	Alarm_Audi	2	3
12.27	Alarm_Fire	2	3
12.6	Alarm_Silent	4	3
12.79	Alarm_Water	1	3
16.55	Alcohol_Off	2	4
17.5	Animal_Pro	2	7
17.51	Arson	4	4
18.58	Assault	2	1
18.8	Assist_O_F	1	1
19.72	Asisst_O_P	2	7
21.65	Assist_Req	2	5
21.75	Attempt_TH	1	4
22.1	Attempt_Lo	3	4
24.25	BOL	0	9
24.26	Bomb_Threat	3	1
24.56	Burg_Com	2	4
25.18	Burg_Res	3	4
26.13	Burg_Vehi	2	4
26.51	Child_Abuse	1	3
27.11	Citizen_Di	2	3
27.15	Coll_Freeway	2	1
28.52	Coll_Hit_A	2	3

28.57	Coll_Major	4	1
29.3	Coll_Minor	3	1
32.07	Coll_Non_I	3	3
32.45	Communication	2	4
33.2	Controlled	2	4
	Custodial		
33.24	Interference	1	4
33.26	Deceased	4	2
37.61	Disorderly	4	2
37.86	Domesitic_V	3	2
39.89	DUI	1	4
40.11	Electrical	1	1
40.16	Embezzlement	1	6
40.18	False_Info	0	7
40.19	Fire_Electric	4	1
40.22	Fire_Unknown	4	2
40.23	Water_Inside	4	4
40.24	Fire_Vehicle_Frwy	4	1
40.35	Fire_Illegal	2	4
40.36	Fire_Threat	4	1
40.42	Fire_Out	3	2
40.51	Fire_Nonthreat	2	3
40.62	Fire_Structure	6	1
40.62	Fire_Alarm_Tamper	1	4
40.7	Fire_Vehicle	3	4
40.78	Fire_Wild	4	1
41.06	Fireworks	2	4
41.1	Forgery	1	7
42.57	Found_Prop	1	7
43.68	Fraud	2	6
43.72	Gas_Inside	2	1
43.79	Gas_Outside	1	2
44.4	Graffiti	1	7
44.41	Hazmat_Threat	3	1
44.51	Hazmat_Nonthreat	2	3
44.61	Emerg_Progress	6	1
44.84	Information	1	9
45.61	Juevnile_P	2	6
45.77	Keep_the_Peace	2	3
45.79	Kidnapping	3	1
45.81	Leaking_Hy	3	6
45.91	Littering_N/A	1	9
46.08	Loitering	2	6

46.89	Lost_Prop	0	7
55.28	Medical_Emerg	2	1
55.29	Medical_Nonemerg	0	3
55.77	MENTAL	2	4
55.92	Misc.	1	7
56.36	Missing_Per	4	1
57.08	MUNI_CODE	2	9
57.09	Mutual_Aid_Fire	3	1
57.81	Noise_Enhance	1	6
58.16	NOISE_2nd	2	6
59	Noise_other	2	6
65.98	Noise_Party	2	6
67.38	Noise_Poli	2	6
69.72	Parking_Pr	1	7
69.73	Posting_Camps	1	7
71	Posting_Ve	1	7
71.15	Probation	3	6
71.17	Prop_Dmg	1	4
71.48	Prowler	3	3
72.29	Public_Ass	1	4
73.02	Public_Wor	1	4
73.04	Recovered	1	7
73.1	Resisting	1	1
73.2	Robbery	6	1
73.22	Search_Warrant	2	4
73.52	Sex_Offense	2	1
73.63	Smoke_Check_In	1	4
73.76	Smoke_Check_out	1	4
73.92	Suicide_Att	3	2
79.57	Suspicious	3	4
79.75	Test	0	9
83.64	Theft	2	4
83.9	Theft_Vehi	2	4
84.56	Threatening	1	4
84.57	Tobacco	1	7
88.7	Towed_Vehi	0	4
90.66	Traffic_Ha	2	4
92.7	Traffic_Of	1	6
95	Trespassing	2	3
97.04	Vandalism	3	4
97.66	Warrant	3	4
97.9	Weapon_Off	2	2
99.93	CTW	2	6

Table 12 - Call Properties (Default)

Note: Often, more officers than the minimum are dispatched, due to the greater-than-average severity of a particular event. This is simulated by giving every call a chance of adding one, two, or even three officers to the parameter above.