Optimizing the Performance of the Dona Ana County Ambulance Service

Final Report

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1. INTRODUCTION

With the rising number of retired baby boomers and a constantly increasing trend in emergency medical service (EMS) demand, ambulance service providers are facing the most critical challenges of their history. In addition, the EMS systems are facing another issue, i.e., the increment of the EMS system operating costs, which are also being impacted by the continuous rising costs of fuel, professional labor, and technology improvement. To overcome these challenges, ambulance service providers must find a way to continuously optimize resources. Therefore, the goal of this research is to improve the ambulance deployment strategy through identifying good locations for the base station of the ambulances and its fleet size so that more accurate deployments of resources can be accomplished. This would reduce operating costs while improving the EMS system reliability.

There are four attributes for a system to be nationally considered as high performance: clinical excellence, response-time reliability, economic efficiency, and customer satisfaction within budget constraints. Among them, the response-time reliability is the main driver of this research. According to the national standard set by the American Ambulance Association (AAA), 90% of EMS request calls within an urban area should be responded within 8-minutes, whereas response times for suburban and rural areas can differ based on the needs and the configuration of each EMS system and as approved by the local medical director (AAA, 2008).

1.1 Current Emergency Medical Services in Doña Ana County

Doña Ana County occupies a total area of 3,815 square miles in south-central New Mexico and is the home to more than 210,000 residents. The County is divided into three distinct ambulance zones, described below as Central, North, and South county (RFP Emergency and Non Emergency Ambulance Transport Services, 2007). The *Central Doña Ana County* is primarily urban and includes many different fire districts. The City of Las Cruces is the county seat and is located in the center of the county, which is the largest user of county ambulance services. Other fire districts included in this zone are Organ, Fairacres, Mesilla, South Valley, Las Alturas, University, Doña Ana, Mesquite, La Mesa, and White Sands. Although White Sands Missile Range is mostly outside of any of the zones, the Central DAC area is the closest one. The *Northern Doña Ana County* is primarily rural and consists of only a few fire districts with a population of less than 2400 in each fire district (2000 Census Population). The fire districts included in this zone are Garfield, Rincon, Hatch, and Radium Springs. The *Southern Doña Ana County* is primarily suburban including fire districts such as Chamberino, La Union, Santa Teresa, Anthony, Chaparral, Sunland Park, Far South, and West Valley. These three ambulance zones are represented as Zone A, Zone B, and Zone C in Figure 1-1. Each of these ambulance zones have been subdivided into smaller response time compliance areas, where there are many different response time divisions in each zone. Each of the response time divisions was assigned according to the radius or the distance between the location of the EMS request call and the place selected as the center of each ambulance zone (see Figure 1-1). However, the County's current setting of the response time divisions is not consistent with the national standards which was set by American Ambulance Association (AAA), where the service area is divided into three divisions (i.e., urban, suburban, and rural) based on population density. According to the national standard, different response time standards are implemented to the three areas divisions.

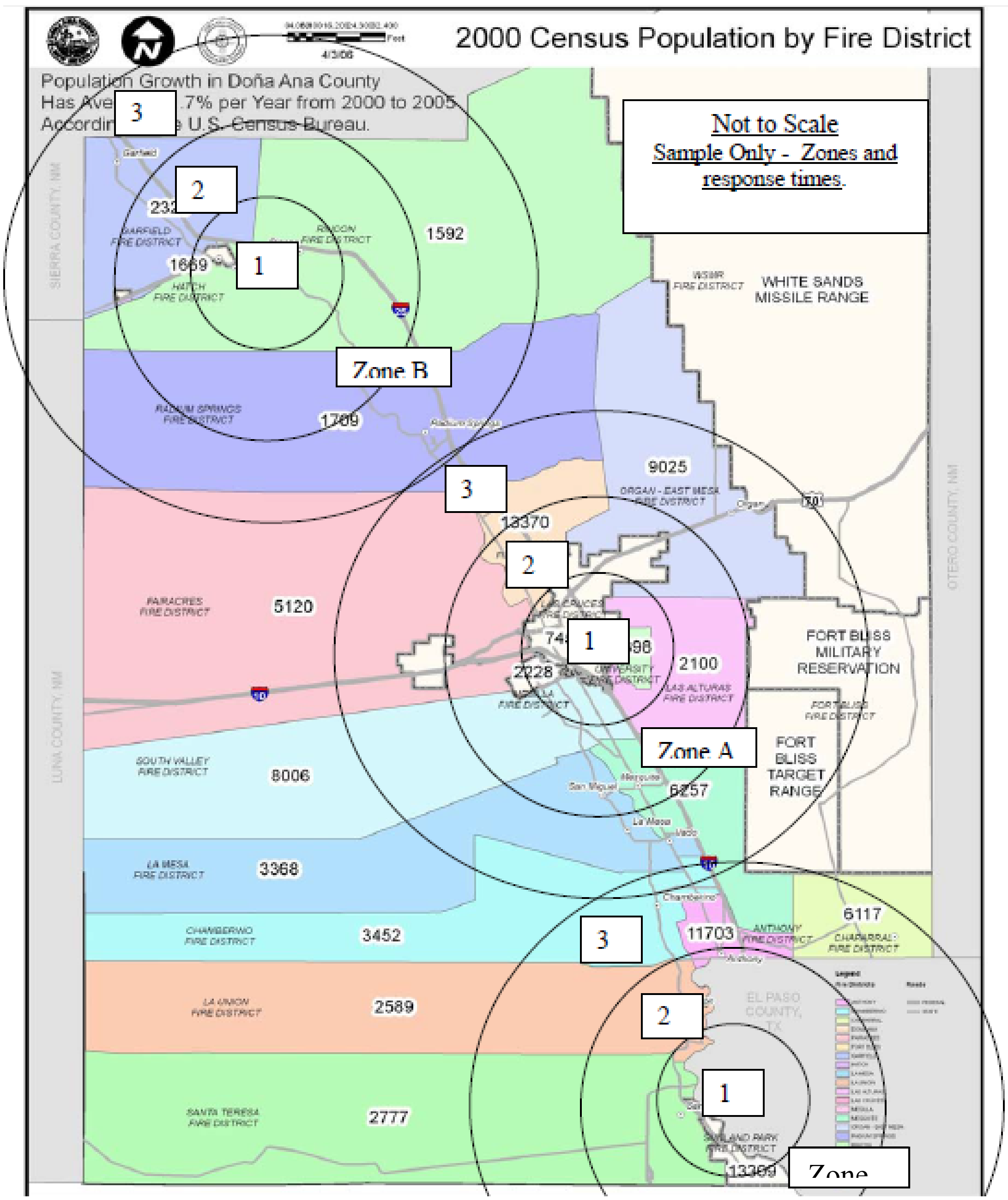


Figure 1-1. Map of response time division (map source: Dona Ana County (2000))

According to Doña Ana County NM Request for Proposal for Emergency and Non-Emergency Ambulance Transport Services (RFP #07-0040), the County considers two types of reporting categories, i.e., *Code1* and *Code3*. The *Code1* is an emergency perceived as a non-life threatening situation. This type of emergency is responded without use of lights and sirens. The *Code3* is an emergency perceived as a life threatening situation. This type of emergency requires the immediate dispatch of an ambulance with use of lights and sirens. While conducting our research, we used 0.82 as the *Code3* speed ratio since the ambulance responding the *Code3* runs faster than the one for the *Code1*. Note that this ratio was estimated based on the actual data.

1.2 Response Time

The primary criterion for responsiveness of emergency services is the response time (Public Technology Inc., 1977). Although the response time is not the only measure of performance, it plays a major role in the patients outcome. Thus, it is important to have a clear definition of what this really means. The ambulance response time is the interval between when the system first gains enough information to initiate a response and the time a properly equipped and staffed ambulance arrives at the scene (Stout, 1987). According to Cummins (1991) the definition of a response time incredibly varies. About half the systems start the response time clock when the call is received, and some systems are at the receipt of dispatch. Yet, others start the clock when the ambulance wheels begin to roll. Note that the Doña Ana County currently adopts the second case. Table 1-1 compares two different standards for each response time compliance areas in the Doña Ana County. One is the County's Standard Response Time (RT) which is based on the radius or the distance between the location of the call and the place selected as the center of each ambulance zone, and the other is the National Standard RT which was set by the population density of the compliance area. Note that the County's Standard RTs were obtained from the AMR Dona Ana County's ARC Report in December, 2013. As it can be seen in the table, in most of the cases, the two standard RTs are quite different each other. The County uses longer Standard RTs for the eight fire districts than the National Standard, and for the others, shorter Standard RTs are used in the County. In this research, we use the National Standard RTs.

Table 1-1. Fire Districts of the Doña Ana County and their Standard RT

Fire Districts	County's Standard RT	Type of Fire Districts	National Standard RT
Anthony	0:12:00	Suburban	0:15:59
Chamberino	0:14:30	Suburban	0:15:59
Chaparral	0:11:45	Suburban	0:15:59
Dona Ana	0:13:45	Suburban	0:15:59
Fair Acres[1]	0:13:30	Urban	0:08:59
Far South	0:12:00	Suburban	0:15:59

Garfield	0:12:15	Rural	0:20:59
HATCH	0:10:15	Rural	0:20:59
La Mesa	0:15:30	Suburban	0:15:59
La Union	0:13:15	Suburban	0:15:59
Las Alturas[1]	0:13:45	Urban	0:08:59
Las Cruces	0:08:00	Urban	0:08:59
Mesilla[1]	0:10:30	Urban	0:08:59
Mesquite[1]	0:16:45	Suburban	0:15:59
NMSU[1]	0:09:30	Urban	0:08:59
Organ[1]	0:16:00	Suburban	0:15:59
Radium Springs[1]	0:19:45	Suburban	0:15:59
Rincon	0:10:30	Rural	0:20:59
Santa Teresa	0:11:30	Suburban	0:15:59
South Valley[1]	0:13:45	Urban	0:08:59
Sunland Park	0:12:45	Suburban	0:15:59

[1] The Dona Ana County's Standard RT is longer than the National Standard for these fire districts

1.3 Response Time as a Performance Measure

There are two general approaches to measuring a response time performance: (1) average value of response time and (2) percent of responses within a defined time limit, i.e., fractile response time, where the fractile expression is the preferred method (Overton and Stout, 2002; Zikmund, 2000). Unlike the average response time, by using the fractile measure, we are able to see how often a benchmark time is achieved. For example, for a target response time set to 8:59, let's suppose that three emergency responses took 3 minutes, 7 minutes, and 13 minutes, respectively. With the average response time of 7:40, it seems that the system is doing great. The value of 0.66-fractile resulted from the fractile calculation, however, showed that only 66% of the responses met the target response time. The average response time is not only a totally misleading indicator of response-time reliability, but is also a clinically inappropriate goal. Systems with similar average response times can deliver widely varying levels of clinical performances to their patients when analyzed using fractile comparisons (Overton and Stout, 2001). According to the First National EMS Systems Survey in 2003, however, only about 3% of the agencies reported fractile calculations of response times. In the project report back in 2012, we recommended the usage of fractile response time as a performance measure (Sohn et al., 2012). We notice that the AMR has been using the fractile measure since then, however, in a somewhat different way. While calculating a fractile measure, the AMR has used the County's Monthly Average RT as a benchmark time, instead of the (National) Standard RT. This might lead to inaccurate response-time reliability.

Table 1-2. Fire Districts of the Doña Ana County and their RT for the Fractile Measure

Fire Districts	County's Standard RT	County's Monthly Average RT	National Standard RT
Anthony	0:12:00	0:10:19	0:15:59
Chamberino	0:14:30	0:15:25	0:15:59
Chaparral	0:11:45	0:11:21	0:15:59
Dona Ana	0:13:45	0:11:14	0:15:59
Fair Acres[1,2]	0:13:30	0:15:39	0:08:59
Far South	0:12:00	0:11:57	0:15:59
Garfield	0:12:15	0:10:10	0:20:59
HATCH	0:10:15	0:08:55	0:20:59
La Mesa[2]	0:15:30	0:18:03	0:15:59
La Union[2]	0:13:15	0:26:56	0:15:59
Las Alturas[1,2]	0:13:45	0:13:15	0:08:59
Las Cruces	0:08:00	0:07:44	0:08:59
Mesilla[1,2]	0:10:30	0:13:56	0:08:59
Mesquite[1]	0:16:45	0:13:08	0:15:59
NMSU[1,2]	0:09:30	0:10:23	0:08:59
Organ[1]	0:16:00	0:15:33	0:15:59
Radium Springs[1]	0:19:45	0:15:34	0:15:59
Rincon	0:10:30	0:10:21	0:20:59
Santa Teresa	0:11:30	0:12:58	0:15:59
South Valley[1]	0:13:45	0:08:37	0:08:59
Sunland Park	0:12:45	0:12:03	0:15:59

[1] The Dona Ana County's Standard RT is longer than the National Standard for these fire districts

[2] The Dona Ana County's Monthly Average RT is longer than the National Standard RT for these fire districts

In Table 1-2, we list all three response times, i.e., County's Standard RT, County's Monthly Average RT, and National Standard RT. Readers can easily see that these three response times are quite different from each other for some cases. As a result, different levels of the response-time reliability can be obtained depending on the choice of the benchmark time. The Doña Ana County currently uses a monthly response time compliance rate of 85% within each division as specified in the First Amendment to the Contract between Doña Ana County and American Medical Response (AMR) from contract # 09-015. In this research, however, the compliance with the minimum of 90 percent standard is used, which is a National Standard.

2. REVIEW OF METHODOLOGY

This section describes essential concepts and background related to some scientific methods used in this research. They include statistical data analyses for homogeneity tests, data clustering algorithm for the natural groupings of the emergency medical service (EMS) request call locations, discrete event simulation, and heuristic algorithm for identifying and evaluating a set of ambulance locations and its fleet size.

2.1 Non-parametric Homogeneity Tests

According to the literature review, normality cannot be assumed for the number of the EMS request calls. Therefore, it is appropriate to assume that emergency calls do not follow any probability distribution, and thus, distribution-free or non-parametric tests seem adequate to be considered. Mann-Whitney and Kruskal-Wallis tests are non-parametric homogeneity tests to determine whether two populations have the same population median or not. The null hypothesis is "the population medians are equal", whereas the alternative hypothesis is "the medians are not equal" (Devore, 2011). We use these non-parametric tests to prove that there is a reliable significant difference in the EMS request call patterns. We provide a brief summary of how these tests work below:

Mann-Whitney test: The Mann-Whitney test is a statistical technique to compare two data groups. The Mann-Whitney test, sometimes also called the Wilcoxon-Mann-Whitney test or the Wilcoxon Rank Sum test, is often interpreted to test whether the median of the distributions are the same. Similar to the Kruskal-Wallis Test, the Mann-Whitney uses non-parametric technique. After ranking the observations, summation of ranking for each group is calculated based on following equations:

$$\begin{cases} U_1 = R_1 - n_1(n_1+1)/2 \\ U_2 = R_2 - n_2(n_2+1)/2 \end{cases} \tag{2-1}$$

where n_i is a sample size for group *i* and R_i is sum of ranks in group *i.* Note that the minimum value of U_i will be used to find the P-value on significance table.

Kruskal-Wallis test: Kruskal-Wallis test is an extension of the Mann-Whitney test for comparing more than two non-parametric data groups. This test is appropriate when the data does not fulfill the assumptions of ANOVA test such as normality and equal variance. The Kruskal-Wallis test is a one way analysis of variance by ranking the data. Note that the ANOVA is a parametric one way analysis of variance for more than two groups. The statistic value will be calculated from the following formula:

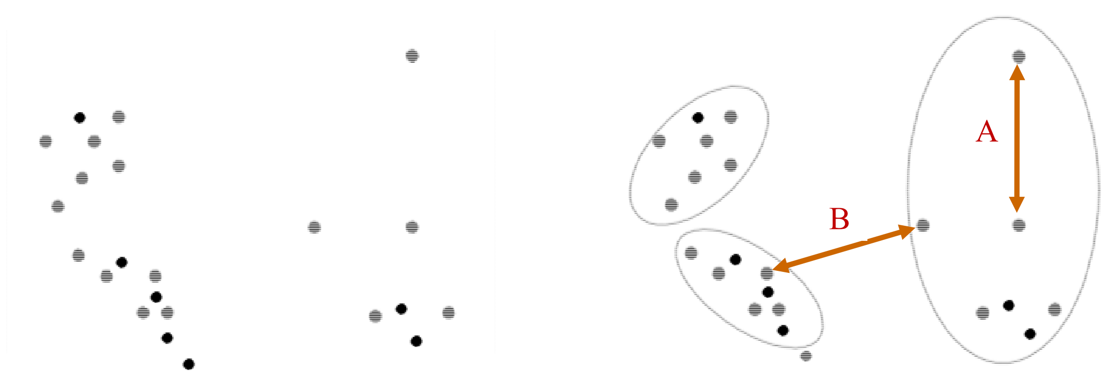
$$k=(N-1)\frac{\sum_{i=1}^{g} n_i(\overline{r_i}-\overline{r})^2}{\sum_{i=1}^{g}\sum_{j=1}^{n_i}(\overline{r_{ij}}-\overline{r})^2} \tag{2-2}$$

where n_i is the number of observations in group i, r_{ij} is the rank (among all observations) of observation j from group i, N is the total number of observations across all groups, $\overline{r_{i\cdot}}=\sum_{j=1}^{n_i} r_{ij}\big/n_i$, and $\overline{r}=(N+1)/2$ is the average of all the r_{ij}. The P-value is calculated based on a probability: $P\left(\chi^2_{g-1}\geq K\right)$.

2.2 Data clustering algorithm

The goal of data clustering, also known as cluster analysis, is to discover the natural groupings of a set of data points, patterns, or objects. The data clustering has been widely used as an efficient tool for dividing and grouping data in many different fields of study, including, but not limited to, social sciences and biology. An operational definition of clustering can be stated as follows and depicted in Figure 1. Given a *representation* of *n* objects, find *K* groups based on a measure of *similarity* such that the similarities between points in the same group are high while the similarities between points in different groups are low (Jain, 2010).

In this research, we use *K-means* clustering algorithm (MacQueen, 1967) which is a greedy algorithm to find a partition such that the distances between the emergency call locations within the same clusters (e.g., 'A' in Figure 2-1) are minimized while the distances between the call locations in different clusters (e.g., 'B' in Figure 2-1) are maximized.



(a) Input data (b) An example of desired clustering

Figure 2-1. Data clustering

K-means clustering

K-means clustering is a method of cluster analysis aiming at partitioning a given number of observations into a certain number of clusters in which each observation belongs to the cluster with the nearest mean (MacQueen, 1967; Tan et al., 2006). The term *K-means* was first used by MacQueen in 1967, though the idea goes back to Steinhaus in 1956. The procedure of the *K-means* algorithm follows a simple and easy way to classify a given data set through a certain number of clusters fixed a priori. Figure 2-2 presents the pseudo-code of the *K-means* algorithm.

```
Select K points as initial centroids given a set of points
Repeat
        Form K clusters by assigning each point to its closest centroid
        Re-compute the centroid of each cluster
Until   the centroids do not change.
```

Figure 2-2. *K-means* clustering algorithm

Let $X = \{x_i\}$, $i = 1,...,n$ be the set of n data points to be clustered into a set of K clusters, $C = \{c_k$, k=1,…, $K\}$. *K-means* algorithm partitions the data such that the squared error between the empirical mean (or center) of a cluster called centroid and the points in the cluster is minimized. Note that the centroid of each cluster is calculated as the mean of all the data points belonging to that cluster. In each iteration, each point is assigned to its nearest centroid according to the Euclidean distance between the two, and then the centroids are re-calculated. That way, *K-means* algorithm returns a set of data groups with a centroid that resembles the nature of the group (or cluster) in general, which means that the data points within a certain group share similar characteristics of other data points within the same group, and thus, the entire cluster is then represented by the centroid. Let μ_k be the mean of cluster c_k. The sum of squared error (SSE) between μ_k and the points in cluster c_k is defined as

$$\sum_{x_i \in c_k} \left\| x_i - \mu_k \right\|^2 \tag{2-3}$$

The smaller value of the within-cluster SSE implies that every point within the cluster is relatively close to the centroid. This will then confirm the centroid is a good representation of all the observations within the cluster. Therefore, the goal of *K-means* algorithm is to minimize the SSE over all K clusters, i.e.,

$$\text{Minimize } \sum_{k=1}^{K} \sum_{x_i \in c_k} \left\| x_i - \mu_k \right\|^2 \tag{2-4}$$

In other words, *K-means* algorithm begins with an initial set of K centroids and iteratively updates it so as to decrease the error function of (2-4). According to Drineas et al. (1999), this minimization problem is known to be an NP-hard problem even for *K*=2. However, due to its ease of interpretation, simplicity of implementation, speed of convergence and adaptability to sparse data, *K-means* algorithm is considered as popular and most commonly used partitioning methods.

2.3 Discrete Event Simulation

A simulation can be defined as numerically exercising the model for the inputs in question to see how they affect the output measures of performance (Law and Kelton, 2000). A computer simulation can be seen as a way to conduct such thought experiments leading to prediction, proof, and discovery (Axelrod, 2003). Unlike the closed form of analytic models, which are often capable of being solved exactly due to a principal understanding of system relationships, complex models that require simulation are often stochastic in nature, preventing any definitive prediction. Rather, inference into a forecasted future is the best that the experiment might provide. As importantly, due to its excursive nature, simulation allows the scientist to discover critical relationships, their interactions, and emergent behaviors, which are not apparent when looking at a temporal snapshot of the holistic system (Axelrod, 2003).

Since the 1970s, scientists have used simulation to conduct experiments, allowing both prediction and the discovery of social changes at the individual level across populations (Zhao, 2000). For example, simulation has played an important role in service-oriented fields such as health care, banking, and education (Vargas, 2002); social analysis such as anthropology, sociology, and economics (Meyer, 2011); and international strategic analysis such as political strategy, military strategy, and military doctrine (Zacharias et al., 2008).

Discrete event simulation (DES) is one of the major paradigms in computational simulation modeling, which built around events and the related states of the system. According to Law and Kelton (2000), the DES concerns the modeling of a system as it evolves over time by representation in which the state variables change instantaneously at separate points in time. The DES is often synonymous with queuing simulations. It provides a proven venue for representing confounded systems in a traceable and rigorous manner that is particularly useful for gaining insight into complex problems. The DES has been used extensively across a breadth of complex problems, including social modeling (Alt and Liebrman, 2010) and education modeling (Marlin and Sohn, 2014). It has also been successfully applied in many sectors of healthcare industries (Marek Lubicz, 1987; Lowery, 1998; James R. Swisher, 2001; Kobi Peleg, 2004; Shane G. Henderson, 2005).

In this research, we develop a DES model and embed it into a greedy like heuristic algorithm to identify and evaluate a set of base locations for ambulances and its fleet size.

3. MODELING DETAILS

3.1 Review of Data

Emergency response data was collected by Mesilla Valley Regional Dispatch Authority (MVRDA) and provided by American Medical Response (AMR). The original data includes 31,614 emergency call records that cover the entire Dona Ana County for a 2 year period from January 1, 2012 to December 31, 2013. The record logs include unit ID, run number, time and date of call, dispatch time, en-route time, arrival time to the scene, departure time to hospital, arrival time at hospital, clear time, disposition, call location, primary unit, target response time, and type of call.

According to literature surveys, there are some critical factors for driving response time performances and reliabilities. They are (1) abilities to understand and predict call volumes based on the time of the day, (2) abilities to understand and predict call volumes based on the days of the week, (3) abilities to understand and predict call volumes based on the month of the year, and (4) abilities to understand and predict geographical locations of the calls. First, we review the County's emergency call volumes and trends based on different times of the day, different days of the week and different month of the year, which are illustrated in Figures 3-1 through 3-3, where the total emergency call count as well as average number of the call count for the 2 year period are recorded.

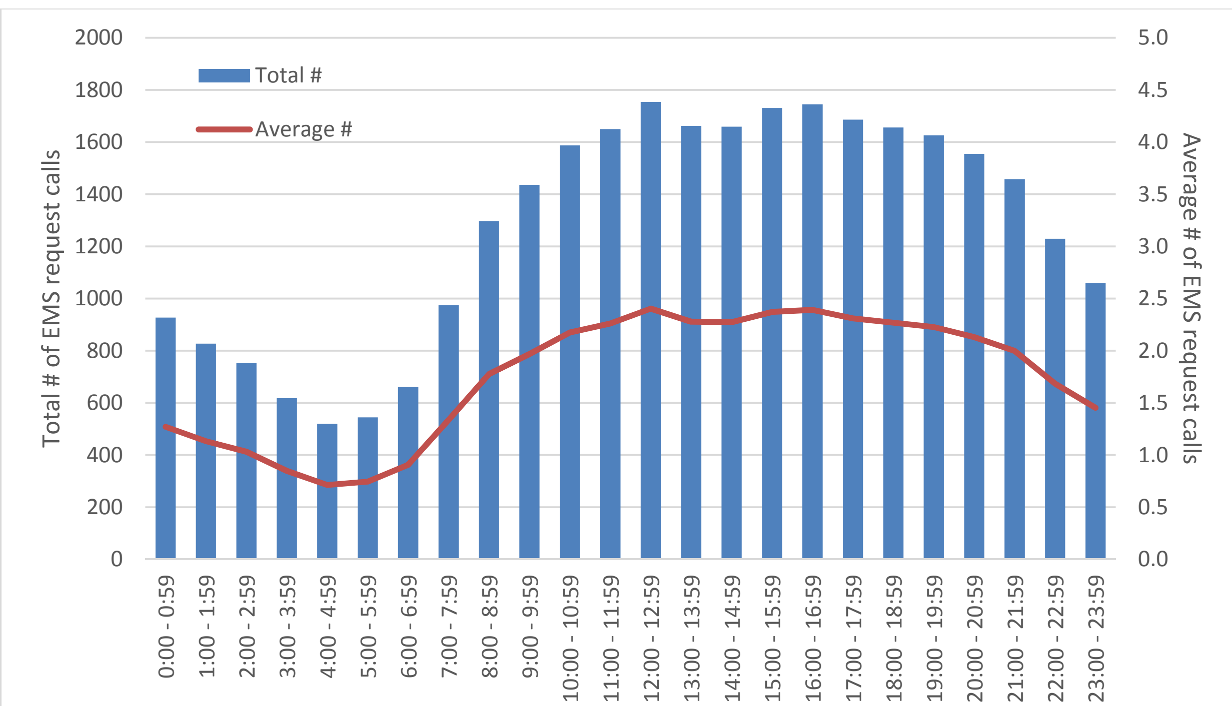


Figure 3-1. Call Volumes upon the Times of the Day (2012-2013)

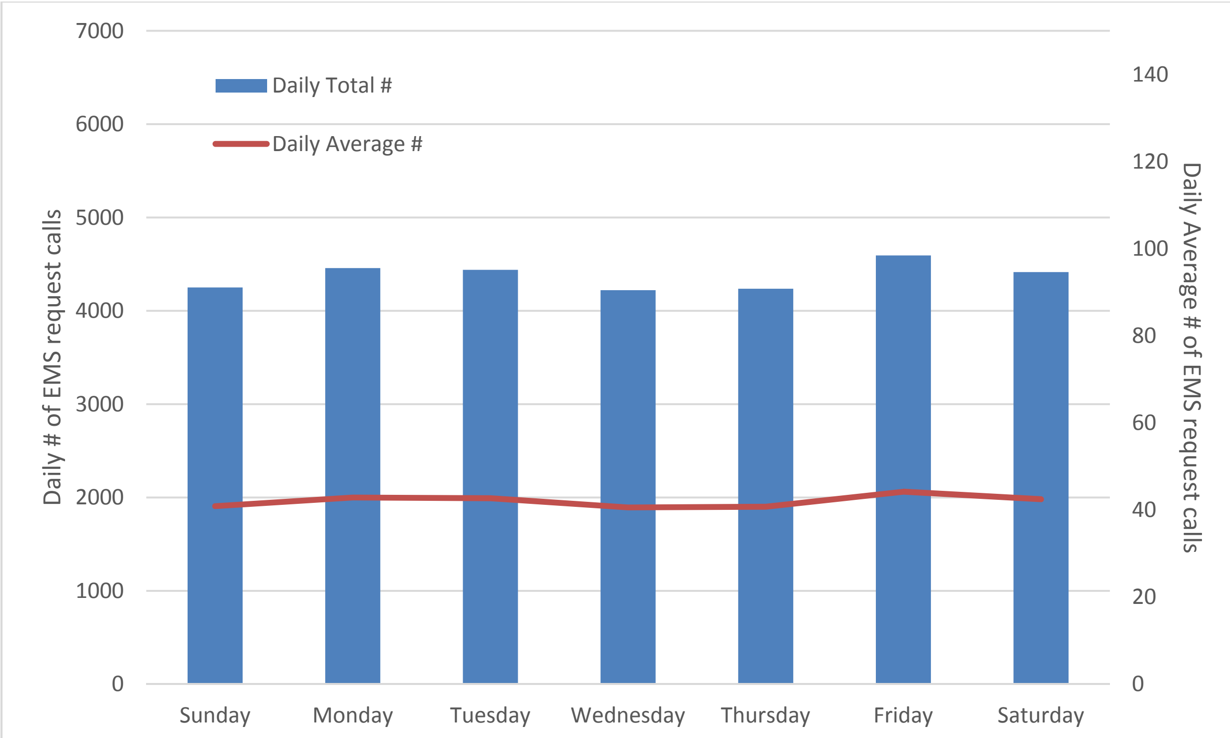


Figure 3-2. Call Volumes upon Day of the Week (2012-2013)

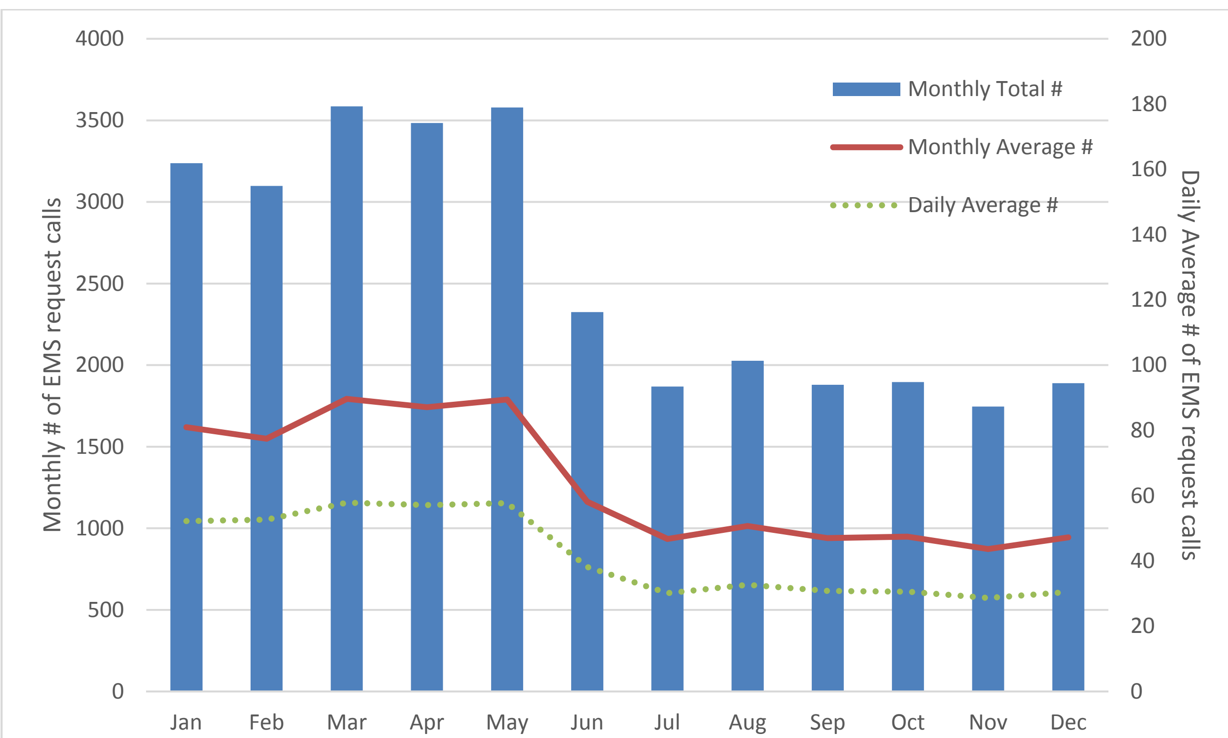


Figure 3-3. Call Volumes upon Month of Year (2012-2013)

About 65% of the calls occurred from 10am to 10pm, and the highest system demand occurred during the lunch time (12pm-1pm) with an hourly average of 2.4 calls (see Figure 3-1). A weekly pattern for the County's EMS request calls are depicted in Figure 3-2. The weekly peak demand occurs on Friday. However, there are no significant differences on the call volume among the seven days. It is also observed that relatively high demands occurred from January through May. Note that more than 55% of the calls were generated in the County during these 5 months.

Next, we have conducted statistical analyses to test if all these patterns are significant, which will provide more accurate information for simulation modeling later. According to the descriptive statistics, most of these finding are supported. In Tables A1 through A3 (see Appendix A), the Kruskal-Wallis test shows that there are significant difference on the call volumes among three groups (i.e., January through May, June, and July through December). However, the homogeneity test on the days of the week failed to reject the null hypothesis. Therefore, it can be concluded that there are no significant variations in the call volumes among the seven days of the week (see Table A4). The homogeneity test in Table A5 also shows that significantly larger demands occurred from 10am – 10pm. In modeling the computer simulation as well as conducting the analysis, therefore, the EMS request call data are grouped into three distinct periods, namely (1) January through May, (2) June, and (3) July through December. Also, the response calls in each of the three periods are grouped into two time frames, namely (1) peak hours (10am-10pm) and (2) non-peak hours (10pm-10am).

Next, we review the County's emergency call volumes and trends based on geographical locations of the calls. We should note that about 30% of the data cannot be used for analysis due to the inaccuracy of the data information, i.e., they were not recognizable on the GIS software. It is also noted that, after the geocoding, we were able to clean the data, i.e., a few call locations were outside the county limits and they were discarded in the analysis. As a result, only 21,507 emergency calls records are used for this study. We visualize the emergency call locations on the map using ArcMaps, a Geographic Information System (GIS) Software (see Figure 3-4). This map provides a good sense of natural groupings of the call locations.

3.2 Clustering of Emergency Call Locations

The goal of this research is to identify good locations for the base station of the County's ambulance vehicles and its fleet size so that more accurate deployments of resources can be accomplished. As the first step, the emergency response data were grouped together based on the similarities of their geographical location. For this purpose, we have applied *K-means* clustering algorithm to our data set to find the partition of emergency call locations such that the distances between the call locations within the same cluster (or group) are minimized.

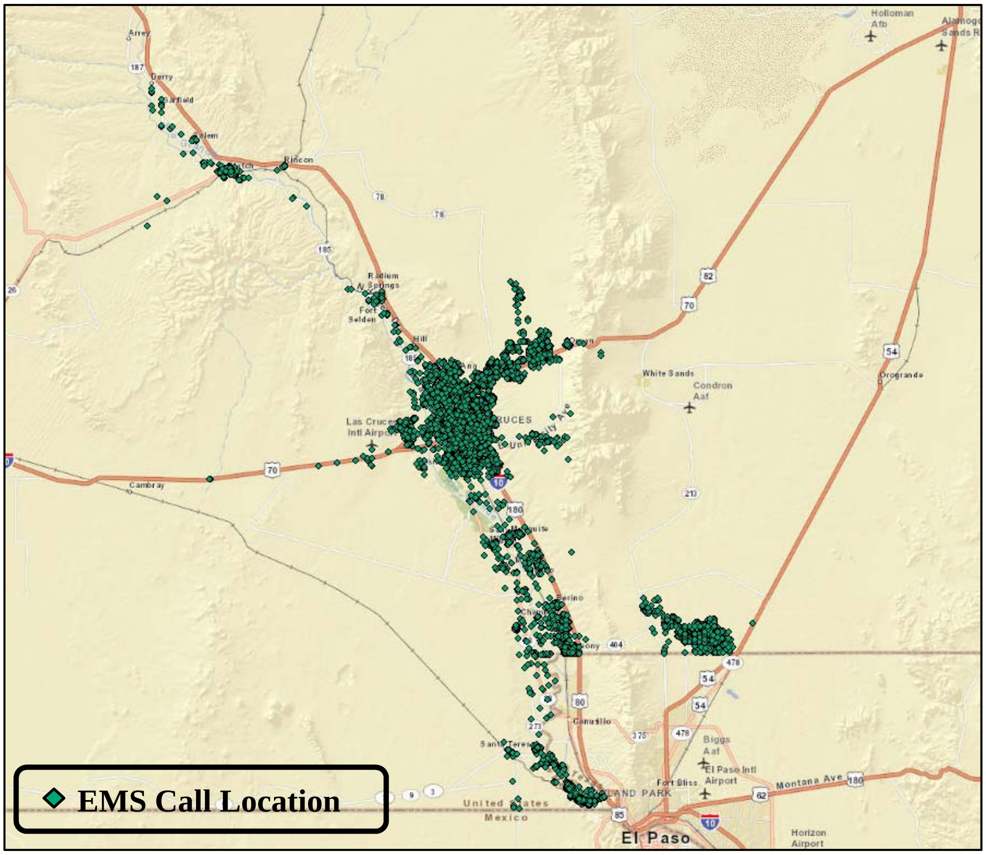


Figure 3-4. Emergency call locations of Doña Ana County (2012-2013)

Note that, in the *K-means* algorithm, initial centroids are often chosen randomly, and the centroid is typically the mean of the points in the cluster. It is also important to note that different initializations in the *K-means* algorithm can lead to different clustering since the algorithm does not guarantee to find the global optima. In order to overcome this shortcoming, for a given number of clusters *K*, we have run the *K-means* algorithm with several different initial partitions, and we chose the one with the smallest value of the sum of squared errors (SSE). We have also run the algorithm independently for different values of *K*, and the partition that appears the most meaningful to the system is selected. Table 3-1 shows, for different values of *K*, the number of emergency calls included in each cluster. We use these values as the weights for each centroid, which will be used to generate emergency calls in the simulation modeling later. Note that a cluster with a heavy weight is highly likely to generate more emergency calls than a cluster with a lighter weight in our simulation model. In general, increasing the value of *K* will reduce the sum of squared error (SSE). However, a good clustering with smaller value of *K* can lead to have a lower SSE than a poor clustering with higher value of *K*. With these in mind, we have carefully chosen *K*=18 as the desired number of clusters for the Dona Ana County's emergency call data. This is because, although the SSE becomes smaller as the value of *K* changes from 18 to 19, the percent of changes in SSE is relatively smaller than other cases (see Table 3-2).

Table 3-1. Summary of *K-means* clustering (Number of the emergency call locations included in each cluster)

# of cluster (*K*)	# of call locations in each cluster
10	4604, 1511, 417, 1272, 3499, 321, 2482, 1145, 4809, 1447
11	1263, 419, 1511, 599, 1145, 321, 2108, 4937, 3993, 1447, 3764
12	418, 566, 1447, 1511, 321, 44, 1145, 6803, 695, 1029, 3692, 3836
13	321, 1145, 575, 1511, 1745, 1447, 336, 3940, 3859, 1919, 1037, 3259, 413
14	996, 3540, 321, 1955, 1100, 4301, 1125, 328, 559, 411, 3871, 1145, 1511, 344
15	1511, 284, 3772, 1919, 321, 415, 2596, 1763, 365, 2144, 2456, 829, 1447, 540, 1145
16	408, 1511, 330, 3579, 343, 1747, 1122, 1145, 559, 1856, 1686, 3374, 982, 2266, 278, 321
17	666, 394, 1511, 275, 1717, 751, 3576, 530, 1684, 2546, 1399, 766, 132, 3379, 321, 1447, 413
18	1416, 1388, 2186, 968, 1068, 275, 1445, 323, 1169, 2802, 1661, 1145, 1162, 413, 445, 557, 321, 2763
19	412, 1910, 1445, 2523, 270, 842, 946, 411, 2930, 550, 1261, 1304, 439, 1145, 321, 663, 1618, 2188, 329
20	564, 751, 394, 2233, 555, 3513, 984, 657, 241, 2137, 321, 1324, 235, 1440, 1764, 216, 283, 3075, 410, 410

Table 3-2. Summary of *K-means* clustering (Sum of Squared Error)

K	SSE value in each cluster	Total SSE	% Change
10	1.91, 2.78, 0.57, 2.26, 3.55, 0.79, 4.13, 1.29, 2.26, 1.10	20.64	
11	2.21, 0.59, 2.78, 1.27, 1.29, 0.79, 2.48, 1.73, 1.76, 1.10, 2.07	18.06	-13
12	0.58, 0.71, 1.10, 2.78, 0.79, 0.28, 1.29, 3.60, 1.46, 0.55, 2.26, 1.71	17.11	-5
13	0.79, 1.29, 0.68, 2.78, 0.65, 1.10, 0.88, 1.52, 1.36, 3.35, 0.56, 0.68, 0.54	16.17	-5
14	0.51, 0.86, 0.79, 0.92, 1.77, 1.66, 0.28, 0.37, 0.65, 0.54, 1.51, 1.29, 2.78, 0.76	14.69	-7
15	2.78, 0.78, 1.01, 0.47, 0.79, 0.56, 0.54, 0.87, 0.80, 1.06, 0.44, 0.33, 1.10, 0.61, 1.29	13.43	-6
16	0.52, 2.78, 0.37, 1.22, 0.76, 0.66, 0.28, 1.29, 0.65, 0.44, 0.79, 0.67, 0.50, 0.39, 0.77, 0.79	12.86	-3
17	0.41, 0.27, 2.78, 0.76, 0.65, 0.27, 1.16, 0.60, 0.30, 0.53, 0.47, 0.25, 0.21, 0.67, 0.79, 1.10, 0.54	11.76	-5
18	0.60, 0.52, 0.33, 0.47, 0.33, 0.76, 1.08, 0.72, 0.28, 0.85, 0.35, 1.29, 0.22, 0.54, 0.34, 0.61, 0.79, 0.28	10.38	-7
19	0.54, 0.43, 1.08, 0.69, 0.75, 0.18, 0.45, 0.05, 0.32, 0.63, 0.26, 0.48, 0.34, 1.29, 0.79, 0.09, 0.74, 0.34, 0.73	10.17	-1
20	1.21, 0.27, 0.27, 0.73, 0.58, 0.63, 0.49, 0.08, 0.40, 0.53, 0.79, 0.41, 0.21, 1.04, 0.40, 0.03, 0.77, 0.44, 0.05, 0.53	9.85	-2

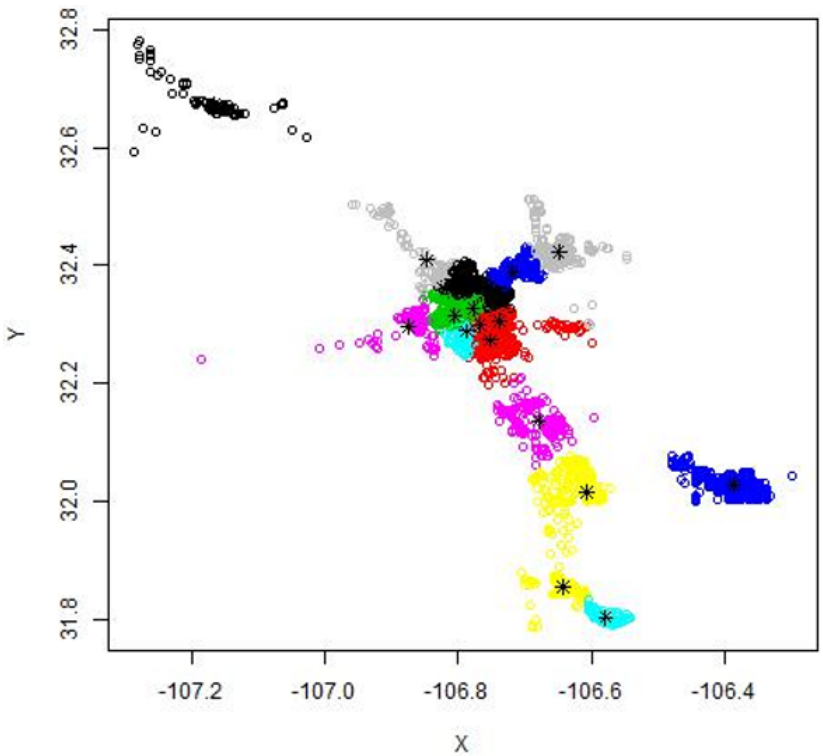


Figure 3-5. 18 clusters and their centroid locations for the County's emergency call data

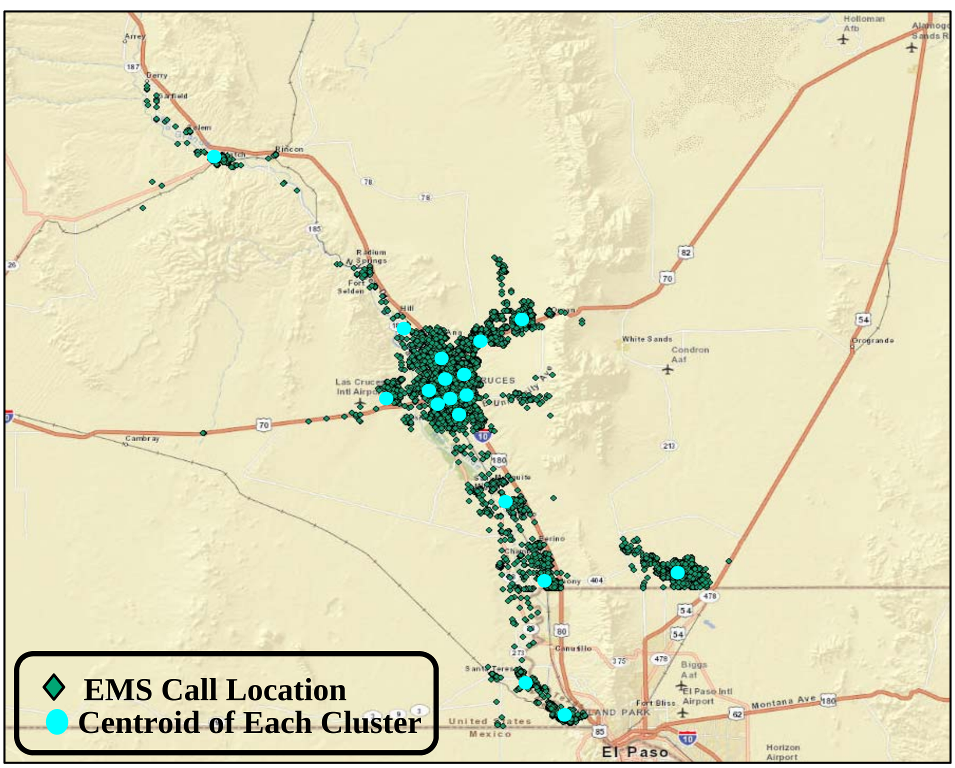


Figure 3-6. 18 centroids as the most representative emergency call locations at the County

The *K-means* clustering algorithm applied to the County's historical emergency call data produces a set of centroids capturing patterns corresponding to the error function in Section 3.1.1. They are mapped in Figure 3-5, where different clusters are represented by different color and 18 centroids are denoted by asterisk. Note that all of the plotted points in the figure are based on their corresponding longitude and latitude, which are represented by X and Y, respectively. All of these 18 centroid locations are specified on the map in Figure 3-6, which helps us for a better understanding of where these points are physically located in the Doña Ana County. In Table 3-3, we show the detailed information of the 18 clusters and their centroid. They include the physical address of each centroid, the classification of each cluster based on population density, the National Standard Response Time (RT) for each cluster, and the name of fire districts included in each cluster.

Table 3-3. Information of the 18 clusters and their centroids

Cluster ID	Physical Address of Each Centroid	Type of Clusters	National Standard RT	Fire Districts included in each cluster
1	600-610 County Road 314, Hatch, NM 87937	Rural	0:20:59	Garfield, Rincon, and Hatch
2	7417 Catalonia Ct, Las Cruces, NM 88005	Suburban	0:15:59	Dona Ana, and Radium Springs
3	6657-6699 Moongate Rd, Las Cruces, NM 88012	Suburban	0:15:59	Organ, and White Sands
4	4646 Calle De Nubes, Las Cruces, NM 88012	Urban	0:08:59	Las Cruces
5	165 Shawnee, Las Cruces, NM 88007	Urban	0:08:59	Las Cruces
6	1145 Sandy-Hill Dr, Las Cruces, NM 88007	Urban	0:08:59	Las Cruces
7	2506 Primavera St, Las Cruces, NM 88007	Urban	0:08:59	Las Cruces, and Fairacres,
8	1960 N Solano Dr, Las Cruces, NM 88001	Urban	0:08:59	Las Cruces
9	2724-2748 Mission Rd, Las Cruces, NM 88011	Urban	0:08:59	Las Cruces
10	1490 Hickory Dr, Las Cruces, NM 88005	Urban	0:08:59	Las Cruces, and Mesilla
11	865 E Idaho Ave, Las Cruces, NM 88001	Urban	0:08:59	Las Cruces
12	2835-2899 Hillrise Dr, Las Cruces, NM 88011	Urban	0:08:59	Las Cruces
13	2518-2524 Espina St, Las Cruces, NM 88001	Urban	0:08:59	Las Cruces, South Valley, Las Alturas, and University
14	10101 New Mexico 478, Mesquite, NM 88048	Suburban	0:15:59	Mesquite, and La Mesa
15	648-654 Crossett Ln, Anthony, NM 88021	Suburban	0:15:59	Chamberino, La Union, and Anthony
16	605-607 E Paloma Blanca Dr, Chaparral, NM 88081	Suburban	0:15:59	Chaparral
17	65 Teresa Paseo Dr, Santa Teresa, NM 88008	Suburban	0:15:59	Santa Teresa
18	2585 McNutt Rd, Sunland Park, NM 88063	Suburban	0:15:59	Sunland Park, Far South, and West Valley

The classification of the 18 centroids which was determined by population density is also depicted in Figure 3-7. Readers are referred to Appendix B to see a clearer view of these locations on the map. Among these 18 service locations, 10 centroids are identified as Urban areas that are located in the center of the county, which includes Las Cruces, Fairacres, Mesilla, South Valley, Las

Alturas, and University fire districts. These 10 centroids are represented by light-green dots in the figure, and we use the Standard RT of 0:08:59. Only one of them is identified as a Rural area which applies to the Standard RT of 0:20:59. This rural area is represented by pink dots in the figure, and Rincon, Hatch, and Garfield fire districts are included in it. The other 7 centroids were classified as Suburban area. Five of them are located in the Southern Doña Ana County (i.e., Mesquite, La Mesa, Chamberino, La Union, Anthony, Chaparral, Santa Teresa, Sunland Park, Far South, and West Valley), and two of them are in the Central Doña Ana County (i.e., Dona Ana, Radium Springs, Organ, and White Sands). These Suburban areas are represented by red dots in the figure and we use 0:15:59 as the Standard RT. All of this classification information will be used for our simulation model later.

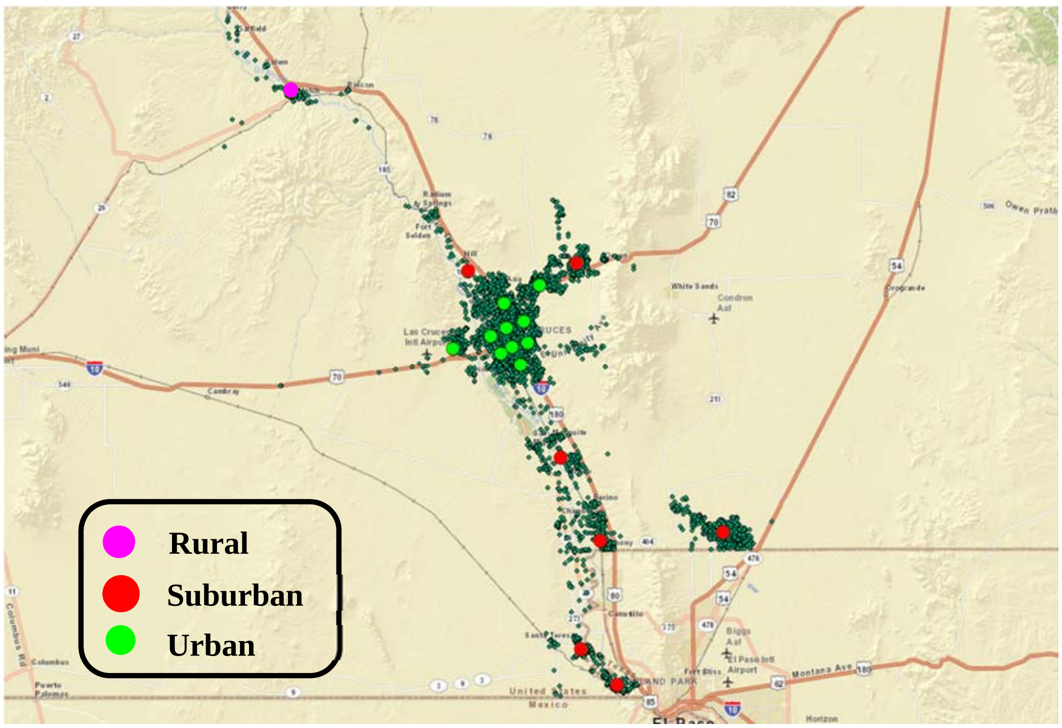


Figure 3-7. Classification of the 18 centroids based on population density

3.3 Candidate Site Stations for Ambulances

The current study includes 27 potential candidate site stations for ambulance vehicles, which were identified by the Dona Ana County and AMR. The detailed information of these site locations are summarized in Table 3-4 and the actual locations are depicted on the map in Figure 3-8. Readers are referred to Appendix C to see a clearer view of these locations on the map, where we provide zoom-in maps for each of the Northern, Central, and Southern Dona Ana County.

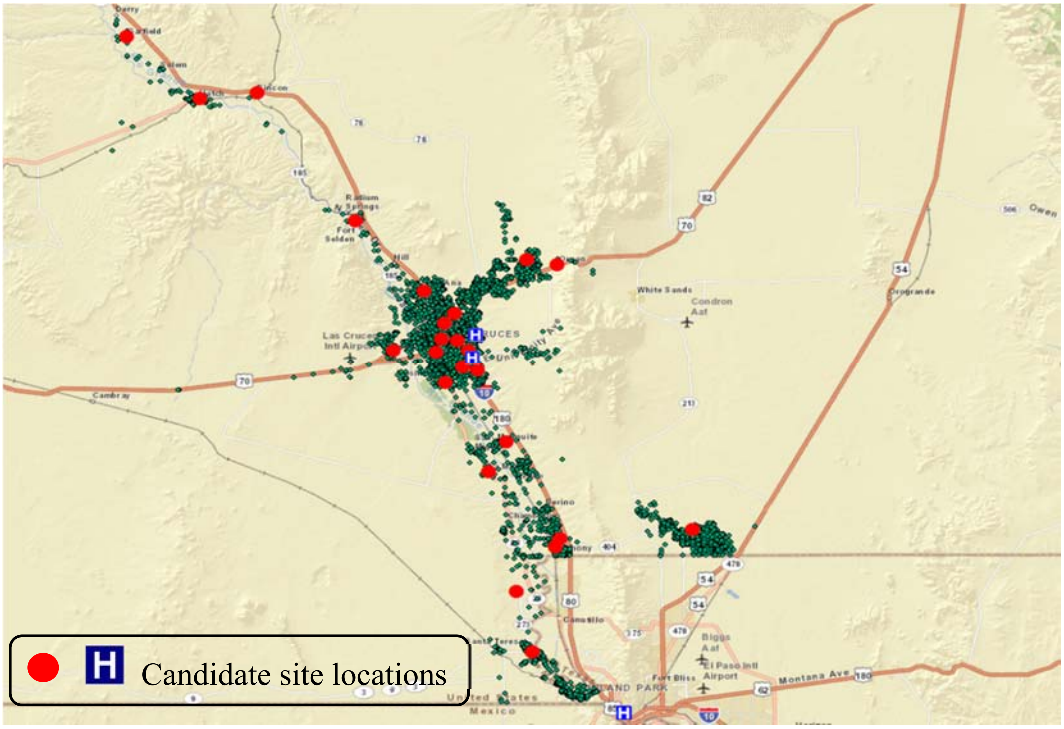


Figure 3-8. Initial 27 candidate site locations including three hospitals

Table 3-4. Information of the 27 potential site locations for ambulances

Site ID	Type	Address
A	Fire Station	216N Franklin St., Hatch, NM
B	Fire Station	601 Dona Ana School Rd, Las Cruces, NM
C	Fire Station	6900 Moongate Rd, Las Cruces, NM
D	Fire Station	2750 Northrise Dr., Las Cruces, NM
E	Fire Station	5208 Quesenberry Lane, Fairacres, NM
F	Fire Station	201 E Picacho Ave, Las Cruces, NM
G	AMR	151 S Walnut, Las Cruces, NM
H	AMR	920 S Valley Dr, Las Cruces, NM
I	Fire Station	2800 Missouri Ave., Las Cruce,s NM
J	Fire Station	1510 Wells St, Las Cruces, NM
K	Fire Station	1 Firehouse Rd., Mesquite, NM
L	AMR	1215 Anthony Dr., Anthony, NM
M	AMR	500 E Lisa Dr., Chaparral, NM
N	Fire Station	350 Telles St., Anthony, NM
O	AMR	5650 McNutt Rd., Sunland Park, NM
H1	Hospital (Mountain View Regional Medical Center)	4311 E Lohman Ave., Las Cruces, NM
H2	Hospital (Memorial Medical Center of Las Cruces)	2450 S Telshor Blvd., Las Cruces, NM
H3	Hospital (Providence Memorial Hospital)	2001 N Oregon St., El Paso, TX
P	Fire Station	1801 Carver Rd., Las Cruces, NM

Q	Fire Station	1055 E O'Hara Rd., Anthony, NM
R	Fire Station	183E San Miguel St., La Mesa, NM
S	Fire Station	5816 Third St., Organ, NM
T	Fire Station	Harlins St., Rincon, NM
U	Fire Station	8920 Hwy 187, Garfield, NM
V	Fire Station	4145 Cholla Rd., Las Cruces, NM
W	AMR	3231N Main St., Las Cruces, NM
X	Fire Station	12211 Leasburg State Park Rd., Radium Springs, NM

3.4 Simulation Modeling

Every response to an emergency medical service (EMS) request proceeds in stages from the receipt of the request through delivery of the patient and return of the responding units to available status. Each ambulance is placed at a pre-determined base station and waits for an EMS request. When an EMS request call arrives, the dispatcher in the control room evaluates the system status and determines the appropriate ambulance to send to the scene. The decisions of dispatching and ambulance location are critical factors in EMS system success. The standard dispatch strategy is to send the closest ambulance that is either idle at its base station or returning from a previous assignment. The ambulance response time is the interval between when the system first gains enough information to initiate a response and the time a properly equipped and staffed ambulance arrives at the scene (Stout, 1987). According to Cummins (1991), the definition of a response time incredibly varies. About half the systems start the response time clock when the call is received, many systems are at the receipt of dispatch, yet still others start the clock when the ambulance wheels begin to roll. In Figure 3-9, these three ambulance response times are specified as ART1, ART2, and ART3, respectively. Note that the Doña Ana County currently adopts the second case, i.e., ART2. Upon arriving on the scene, ambulance service is provided. After initial treatment at the scene, the ambulance may or may not provide transport to a hospital. If transport is not required, the ambulance returns directly to its base from the scene. Otherwise, the ambulance transports the patient to a hospital, and then returns to its base station. In either case, the ambulance vehicle goes into an idle state and is considered available to receive another call as soon as it begins returning to base. Figure 3-9 shows the basic framework of a single ambulance dispatch and service delivery process.

One common assumption in EMS system evaluation is that EMS request calls come into the system according to a Poisson process. This assumption follows intuitively since there is a large population in the area and each individual person has a certain probability of requiring the EMS service. Therefore, we use exponential distribution for the inter-arrival process of the EMS request calls in the simulation modeling. In Table D1 of Appendix D, we provide the inter-arrival rates that have been used in this study for the six different groups (i.e., Code3 in Jan – May, Code3 in Jun, Code3 in Jul – Dec, Code1 in Jan – May, Code1 in Jun, and Code1 in Jul – Dec).

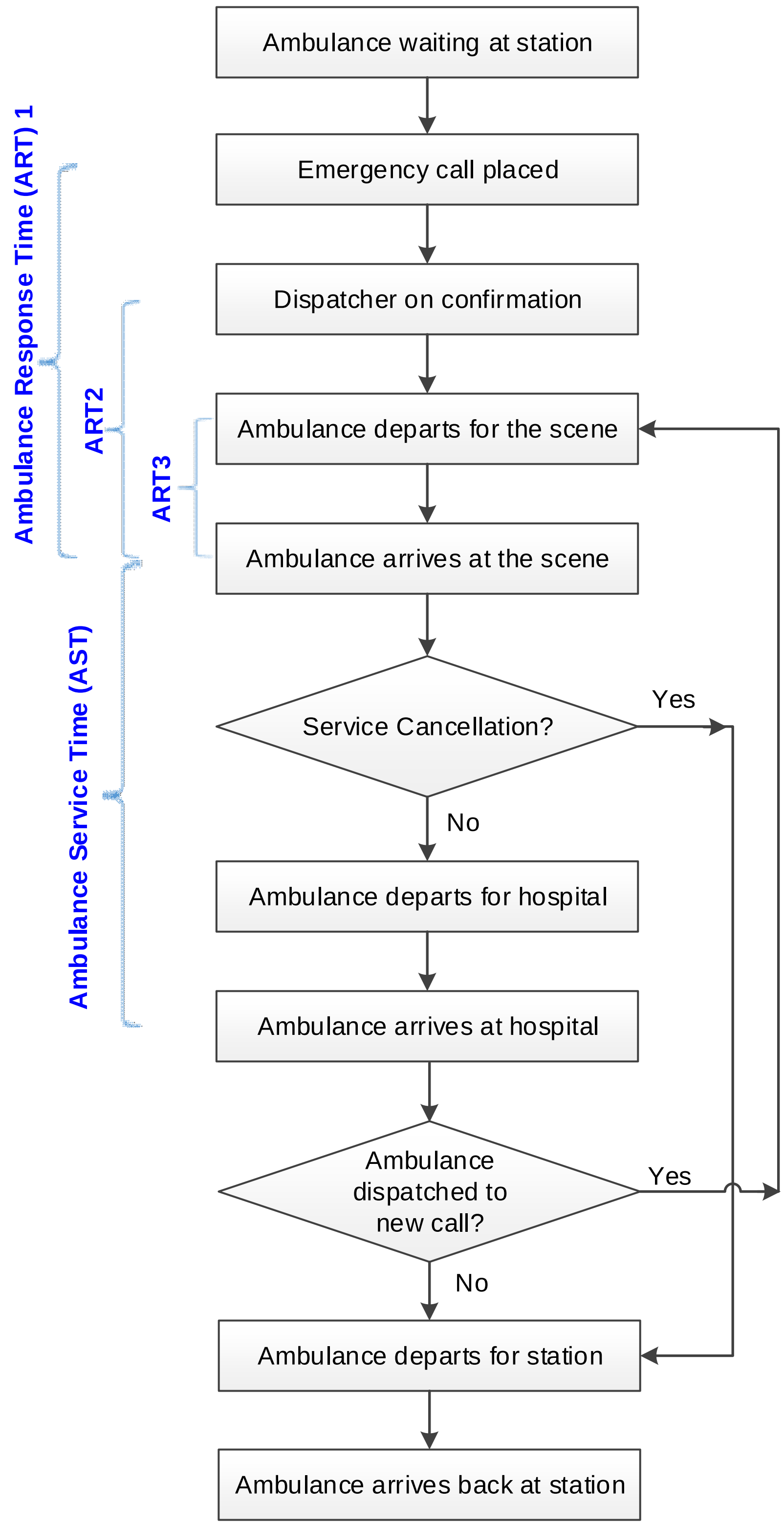


Figure 3-9. Ambulance service process

Once the system receives the call, it enters random process to simulate the time that the dispatcher spends for processing the call. The idle ambulance with the shortest expected travel time to the scene is dispatched and, at the same time, the ambulance response time is started. Note that the Code3 calls have higher priority, i.e., Code3 calls preempt Code1. If the ambulance is located at the pre-determined base station, a random delaying process is modeled to represent time to dispatch. If the ambulance is on the road returning to its base station, zero minute is assigned as the dispatching time. The ambulance travel time is modeled based on the information provided by Google Traffic Maps. The time with patient at the scene is modeled by a random delaying process. While transporting the patient to the closest hospital, the travel time is also modeled by the information provided by Google Traffic Maps. The simulation model also uses a random delaying process for modeling the time in the hospital. In Table D2, we give detailed information about the probability distributions for each random process used in the simulation model (see Appendix D).

3.5 Discrete event simulation (DES) architecture

As shown in Figure 3-10, the simulation model is composed of three primary modules, ambulance, patient, and control center modules. Interaction between modules is essential as the dispatching decision is dependent on availability of the ambulance and the patient's medical status.

Each ambulance is placed at a pre-determined base station and waits for an EMS request. The ambulance starts its task upon request from the control center. First, it arrives at the scene. Then, it provides initial medical treatment. After the initial treatment at the scene, the ambulance may or may not provide transportation to a hospital. If transportation is not required, the ambulance is assigned to another call or returns directly to its base from the scene. Otherwise, the ambulance transports the patient to a hospital, and then either provides inter-facility transportation service, responds to another call, or returns to its base station.

Each patient enters the system by generating an EMS request call. After a certain period of time waiting, the patient receives initial treatment at the scene. If the patient requires a higher level of medical treatment, then he/she is transported to a hospital. Otherwise, the patient exits the EMS system.

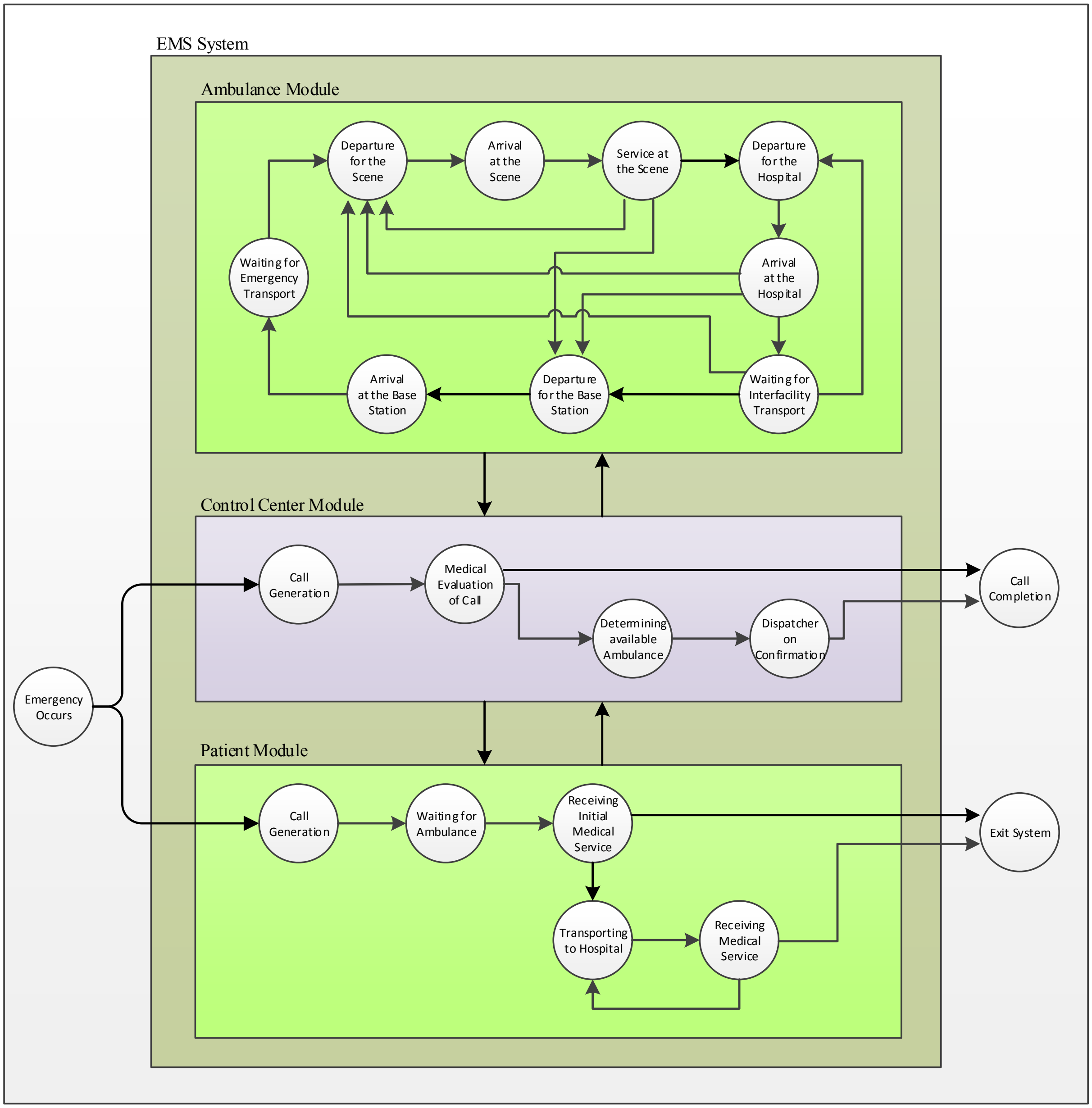


Figure 3-10. Event diagram for the basic EMS system module.

The dispatcher at the control center is the decision core of the entire EMS system. When an EMS request call arrives, the dispatcher evaluates the system status and determines the appropriate ambulance to send to the scene. The decisions of dispatching and ambulance location are critical factors in the success of the EMS system. The standard dispatch strategy is to send the closest ambulance that is either idle at its base station or returning from a previous assignment.

3.6 Hybrid DES/Heuristic algorithm

The EMS system configuration resulted from the simulation run may be feasible or infeasible with respect to satisfying the target fractile response time. In this section, we present a greedy like heuristic algorithm that aims to modify the system configuration resulted from the simulation run in order to meet the targeted fractile value of the response time. The basic idea is that the new system configuration is obtained by moving a set of ambulance vehicles between potential location sites or adding a set of ambulances on potential site locations. The complete details of the algorithm are depicted in Figure 3-10 and described as below:

Step 1: Initialization

We set the target fractile value for the County and the target response time for urban, suburban, and rural area.

Step 2: Clustering the call locations & identifying the centroids of each cluster

The emergency response data are grouped together based on the similarities of their geographical location. We use the *K-means* clustering algorithm for this purpose. We also identify the center of each group (cluster) called centroid. The centroid is the most representative point within the group of data points. We initialize the system configuration counter i to 1 and feasibility checking counter j to zero and incumbent solution counter s to zero and set k to zero where k is a counter that is used in testing for “stalling”, i.e., a failure to finding a feasible solution.

Step 3: Locating each ambulance

Each ambulance is randomly allocated to potential site locations.

Step 4: Running simulation

We run simulation and record the fractile value of the system configuration that resulted from the simulation run.

Step 5: Checking feasibility

If the algorithm does not have an incumbent solution yet (i.e., $s = 0$), check the following:

(a) If the current system configuration satisfies the target fractile value and the feasibility check is not performed yet (i.e., j=0), decrement the system configuration counter i by 1, increment the feasibility checking counter j by 1, and eliminate one ambulance from the least busy station and go on to Step 4.

(b) If the current system configuration satisfies the target fractile value and the feasibility check is performed (i.e.,$j \neq 0$), go on to Step 6.

(c) If the current system configuration does not satisfy the target fractile value and feasibility check is not performed yet (i.e., j=0), increment i by 1 and increment the feasibility checking counter j by 1. Add one ambulance to the busiest station, increment the stalling counter k by 1, and go on to Step 4.

(d) If the current system configuration does not satisfy the target fractile value and the feasibility check is performed (i.e.,$j \neq 0$), test for algorithm stalling.

(d1) If the algorithm has failed to find a feasible solution in a specified number of iterations, then we conclude that there is no way of obtaining a feasible solution and start the algorithm over with a different system configuration. That is, if $k > \lambda$, then go on to Step 3. Here, λ is a pre-determined number of iterations.

(d2) If $k \leq \lambda$, then add one ambulance to the busiest station and increment the stalling counter k by 1 and go on to Step 4.

If the algorithm has an incumbent solution (i.e., $s \neq 0$), check the following:

(e) If the System Configuration #A has the higher fractile value than both Configurations #B and #C, it is concluded that the System Configuration #A is the best solution.

(f) If either (or both) system configurations #B or #C is better than the Configuration #A, go on to Step (5a).

Step 6: Identifying incumbent solution

An incumbent solution is identified and recorded as System Configuration #A and its fractile value is recorded.

Step 7: Searching for a better solution

(a) Move an ambulance vehicle from the least busy station to the nearest neighbor station, name it System Configuration #B, and go on to Step 4.

(b) Move an ambulance vehicle from the least busy station to the busiest station, name it System Configuration #C, and go on to Step 4.

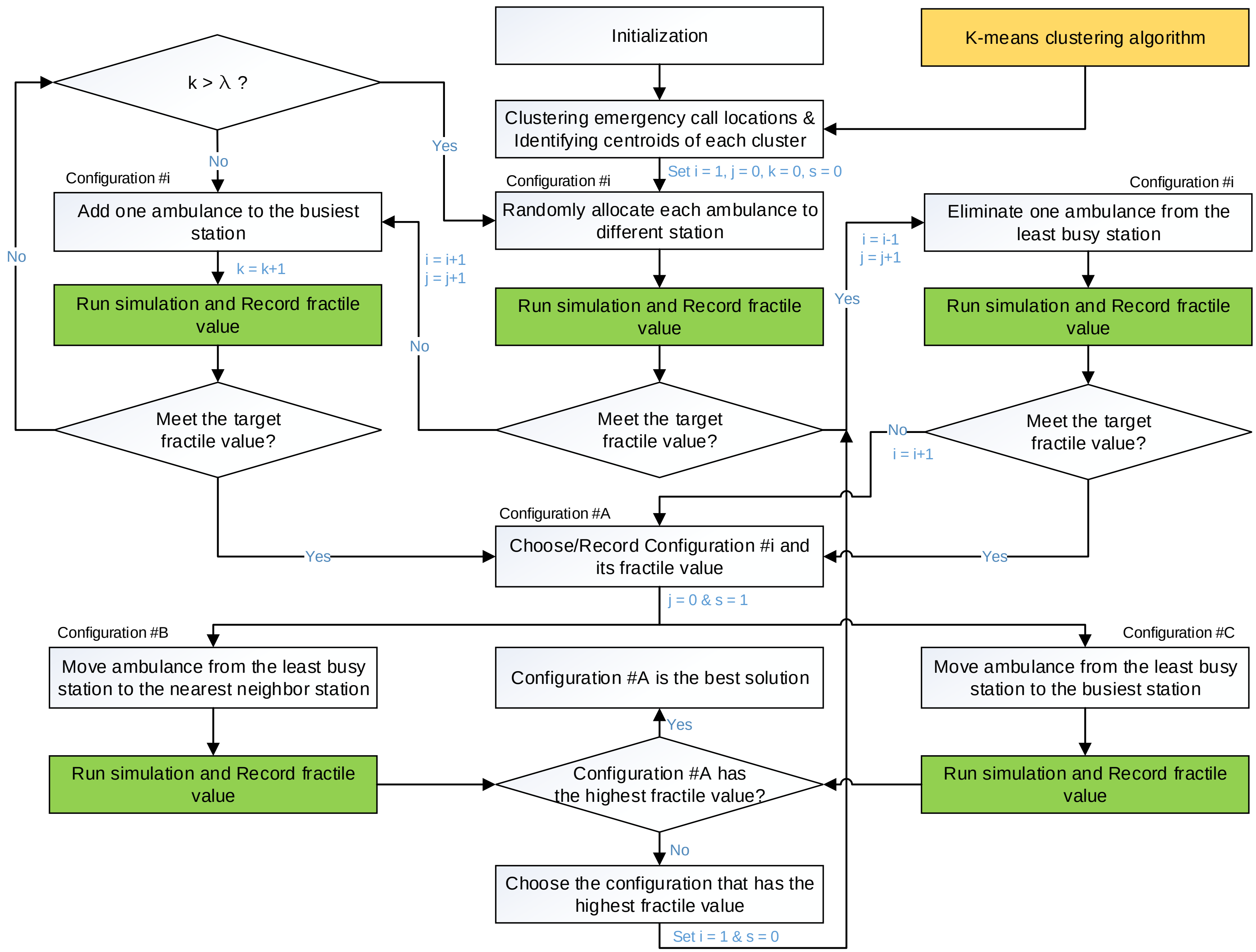


Figure 3-10. Hybrid DES/Greedy Heuristic framework

4. RESULTS AND DISCUSSION

The goal of this research is to identify good locations for the base station of the Dona Ana County's ambulance vehicles and its fleet size so that more accurate deployments of resources can be accomplished. While conducting the analysis, the analysis periods are broken down to three distinct periods, namely, January through May, June, and July through December, and then these three periods are subdivided into peak hours (10am-10pm) and non-peak hours (10pm-10am). The hybrid DES/Heuristic algorithm was implemented on randomly generated data, and we have obtained the best system configuration for each of the six different time frames. In the following sections, all of these results are discussed, and their system performances are compared to the ones from the County's current system configuration.

4.1 System Configuration during peak-hours from January to May

First, we discuss the County's EMS System configuration during the peak-hours, i.e., 10am-10pm, from January to May. During this time frame, the Dona Ana County operates a fleet of 10 ambulance vehicles. According to the simulation results, with the current setting, i.e., $SYS_{current}$ as shown in Table 4-1, only the Rural area met the National Standard of 90% fractile. Neither the Urban nor Suburban areas did not meet the minimum compliance rate. The proposed DES/Heuristic algorithm is able to find a feasible solution (i.e., $SYS_{proposed\_best}$), which satisfies the minimum compliance rate for all three service areas (see Table 4-1). It recommends operation of 11 ambulances and records the fractile rates of 93.12%, 91.13% and 97.9% for Urban, Suburban, and Rural areas, respectively, and overall 92.7%, as well. The corresponding 95% confidence interval (CI) is between 92.34% and 93.60%. Since the County currently operates only 10 ambulances, for the comparison purpose, we also provide a system arrangement, which utilizes only 10 ambulances (i.e., $SYS_{proposed\_10}$). With this modification (i.e., $SYS_{proposed\_10}$), the proposed system did not meet the minimum compliance rate of 90% in the Suburban area. However, the recorded values of the Fractile of RTs in the Urban and Suburban areas are a lot higher than the ones from the current system. The detailed arrangements of the three different solutions are shown in Table 4-2 and visualized on the maps in Figures 4-1 and 4-2.

Table 4-1. Performance Comparison (January – May during peak-hours)

System Configuration	# of Ambulances Required	Fractile of RT (%)					Average RT (min)	
		Urban	Suburban	Rural	Overall Average	95% CI	Overall Average	95% CI
$SYS_{current}$	10	78.35	80.33	98.79	79.14	78.25-80.03	9.52	9.27-9.76
$SYS_{proposed\_10}$	10	92.91	87.54	98.11	91.94	91.56-92.32	6.50	6.42-6.58
$SYS_{proposed\_best}$	11	93.12	91.13	97.9	92.7	92.34-93.60	6.39	6.27-6.50

Table 4-2. Three Different System Configurations (January – May during peak-hours)

Site ID	Address	$SYS_{current}$	$SYS_{proposed\_10}$	$SYS_{proposed\_best}$
A	216N Franklin St., Hatch, NM	X	X	X
B	601 Dona Ana School Rd, Las Cruces, NM		X	X
C	6900 Moongate Rd, Las Cruces, NM			
D	2750 Northrise Dr., Las Cruces, NM		X	X
E	5208 Quesenberry Lane, Fairacres, NM			
F	201 E Picacho Ave, Las Cruces, NM	X	X	X
G	151 S Walnut, Las Cruces, NM	X	X	X
H	920 S Valley Dr, Las Cruces, NM	X	X	X
I	2800 Missouri Ave., Las Cruce,s NM		X	X
J	1510 Wells St, Las Cruces, NM		X	X
K	1 Firehouse Rd., Mesquite, NM			
L	1215 Anthony Dr., Anthony, NM	X		X
M	500 E Lisa Dr., Chaparral, NM	X	X	X
N	350 Telles St., Anthony, NM			
O	5650 McNutt Rd., Sunland Park, NM	X	X	X
H1	4311 E Lohman Ave., Las Cruces, NM			
H2	2450 S Telshor Blvd., Las Cruces, NM	X		
H3	2001 N Oregon St., El Paso, TX			
P	1801 Carver Rd., Las Cruces, NM			
Q	1055 E O'Hara Rd., Anthony, NM			
R	183E San Miguel St., La Mesa, NM			
S	5816 Third St., Organ, NM			
T	Harlins St., Rincon, NM			
U	8920 Hwy 187, Garfield, NM			
V	4145 Cholla Rd., Las Cruces, NM			
W	3231N Main St., Las Cruces, NM	X		
X	12212 Leasburg State Park Rd., Radium Springs, NM	X		
	Total number of ambulance vehicles used	10	10	11

The reason for these improvements can be described as follows. First, we should keep in mind that the Las Cruces fire district is the largest user of county ambulance services with more than 65% of all county ambulance responses put together. The proposed EMS systems deploys six ambulances in the Urban area, while the County's current system deploys five (see Table 4-2 and Figure 4-1). That is, instead of locating one ambulance at the Memorial Medical Center, the proposed system locates two ambulances in the southern area of the City of Las Cruces, i.e., one at the Wells Street and another at the Missouri Avenue. This change resulted in a significant improvement on the performance of the County's EMS in the Urban area as well as the Suburban area, which covers Las Cruces, Las Alturas, South Valley, Mesilla, University, La Mesa, Mesquite, and Chamberino.

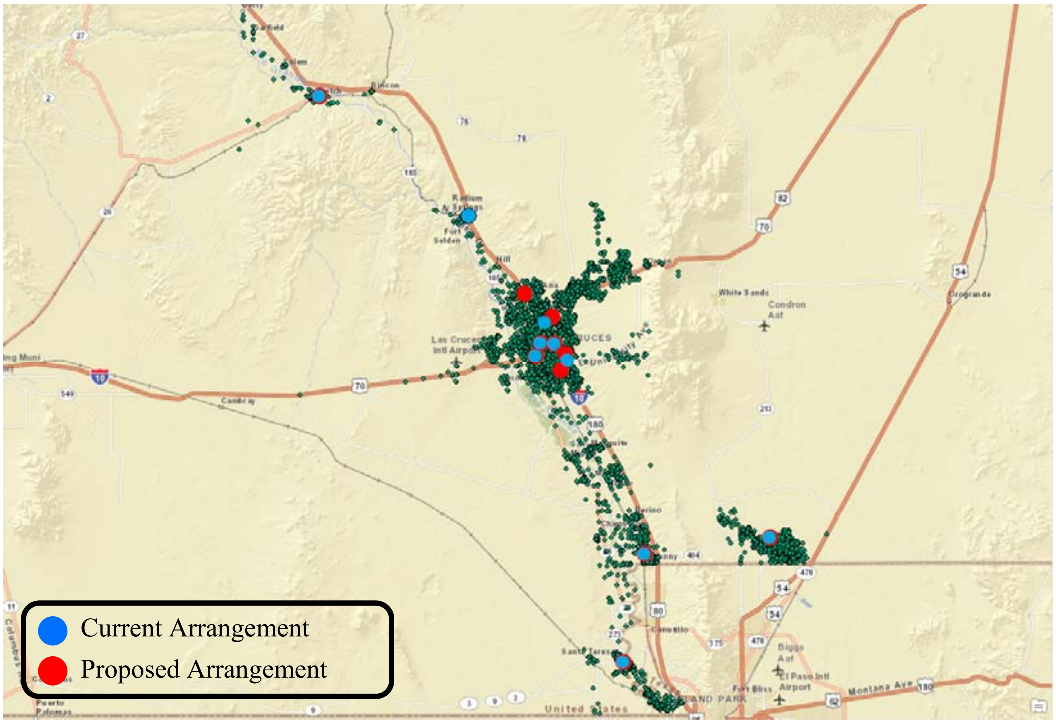


Figure 4-1. Current vs. Proposed System Configurations (January – May during peak-hours)

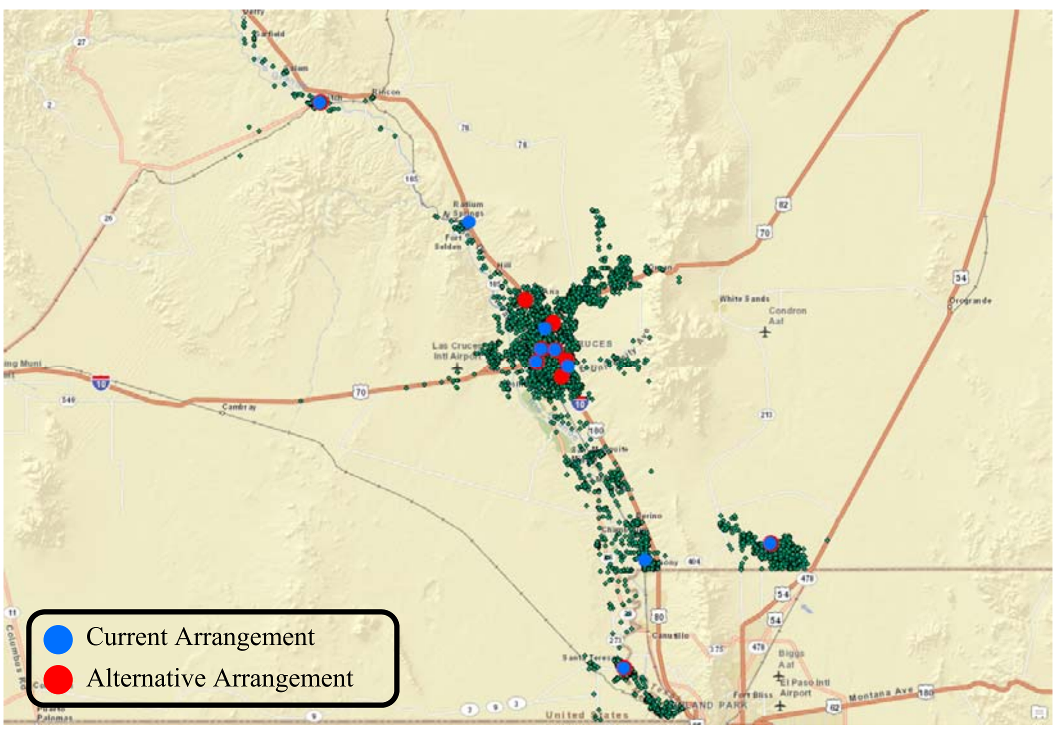


Figure 4-2. Current vs. Alternative System Configurations (January – May during peak-hours)

Also, the proposed system locates one ambulance in the Dona Ana fire district instead of the Radium Springs fire district, which made the system handle a relatively larger number of EMS calls in the Suburban area (such as Dona Ana, Organ, and Fairacres fire districts), as well as the Urban area (such as Northeast area of the Las Cruces fire district, i.e., the Highway 70 area). As a result, the overall average of the fractile value from the proposed system exceeds the minimum compliance rate of 90%. Table 4-1 also includes average RT and its 95% CI as a reference.

If the county has to deploy only ten ambulances, we recommend that the County removes one ambulance from the Anthony fire district (see Figure 4-2). According to the simulation result in Table 4-1 (i.e., $SYS_{proposed\_10}$), the Suburban area won't meet the National Standard RT with this change. However, the system performance is still a lot better than the one from the County's current system.

4.2 System Configuration during peak-hours in June

Now we discuss the County's EMS System configuration for the month of June during the peak-hours, i.e., 10am-10pm. During this time frame, the Dona Ana County currently deploys 10 ambulance vehicles. According to the simulation results, at the Urban and Suburban areas, the County's current system did not meet the minimum compliance rate. Even though the proposed system operates only 9 ambulance vehicles, it satisfies the minimum compliance rate for all three service areas (see Table 4-3). It records the fractile rates of 92.42%, 93.8%, 100%, and 92.88% for Urban, Suburban, Rural, and overall, respectively. The 95% confidence interval (CI) is between 92.13% and 93.63%. The detailed arrangements of the proposed system as well as the current system are shown in Table 4-4 and visualized on the maps in Figures 4-3 and 4-4. We should keep in mind that the Las Cruces fire district is the largest user of county ambulance services with more than 65% of all county ambulance responses put together. Like the County's current system, the proposed system locates five ambulances in the Urban area, but in a slightly different way. That is, instead of considering the Memorial Medical Center and the South Walnut Street as site locations, the proposed system locates one ambulance at Wells Street and another at Missouri Avenue. This change made a significant improvement on the performance of the County's EMS in the Urban area as well as the Suburban area that covers Las Cruces, Las Alturas, South Valley, Mesilla, University, La Mesa, Mesquite, and Chamberino. Even though the proposed system does not locate any ambulances at the Radium Springs, it can still meet the minimum compliance rate for all three service areas (See Table 4-3).

If the County wants to keep using 10 ambulances during this time frame, we recommend the addition of one ambulance to the Radium Springs fire district or the South Walnut Street in the Las Cruces fire district. However, with this extra ambulance, we may not expect a significant improvement on the system performance. As an example, we provided another system configuration with 10 ambulances (i.e., $SYS_{proposed\_10}$) by adding one ambulance to the South Walnut

Street (see Table 4-3). As it can be seen in the table, we observe no big improvement on the system performance with this extra ambulance.

Table 4-3. Performance Comparison (June during peak-hours)

System Configuration	# of Ambulances Required	Fractile of RT (%)					Average RT (min)	
		Urban	Suburban	Rural	Overall Average	95% CI	Overall Average	95% CI
SYS *current*	10	80.83	80.63	98	81.13	78.84-83.42	8.85	8.2-9.51
SYS *proposed_best*	9	92.42	93.8	1	92.88	92.13-93.63	6.35	6.16-6.54
SYS *proposed_10*	10	93.92	93.92	99.17	93.97	93.45-94.49	5.98	5.83-6.14

Table 4-4. Three Different System Configurations (June during peak-hours)

Site ID	Address	*SYS* *current*	*SYS* *proposed_best*	*SYS* *proposed_10*
A	216N Franklin St., Hatch, NM	X	X	X
B	601 Dona Ana School Rd, Las Cruces, NM			
C	6900 Moongate Rd, Las Cruces, NM			
D	2750 Northrise Dr., Las Cruces, NM		X	X
E	5208 Quesenberry Lane, Fairacres, NM			
F	201 E Picacho Ave, Las Cruces, NM	X	X	X
G	151 S Walnut, Las Cruces, NM	X		X
H	920 S Valley Dr, Las Cruces, NM	X	X	X
I	2800 Missouri Ave., Las Cruce,s NM		X	X
J	1510 Wells St, Las Cruces, NM		X	X
K	1 Firehouse Rd., Mesquite, NM			
L	1215 Anthony Dr., Anthony, NM	X	X	X
M	500 E Lisa Dr., Chaparral, NM	X	X	X
N	350 Telles St., Anthony, NM			
O	5650 McNutt Rd., Sunland Park, NM	X	X	X
H1	4311 E Lohman Ave., Las Cruces, NM			
H2	2450 S Telshor Blvd., Las Cruces, NM	X		
H3	2001 N Oregon St., El Paso, TX			
P	1801 Carver Rd., Las Cruces, NM			
Q	1055 E O'Hara Rd., Anthony, NM			
R	183E San Miguel St., La Mesa, NM			
S	5816 Third St., Organ, NM			
T	Harlins St., Rincon, NM			
U	8920 Hwy 187, Garfield, NM			
V	4145 Cholla Rd., Las Cruces, NM			
W	3231N Main St., Las Cruces, NM	X		
X	12212 Leasburg State Park Rd., Radium Springs, NM	X		
	Total number of ambulance vehicles used	10	9	10

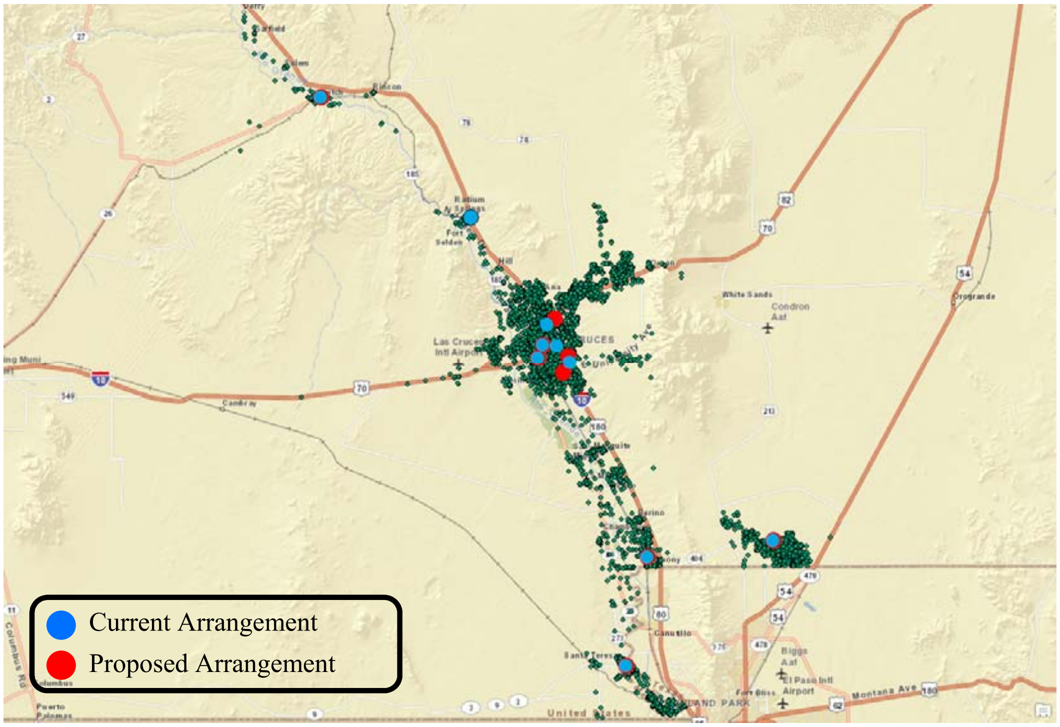


Figure 4-3. Current vs. Proposed System Configurations (June during peak-hours)

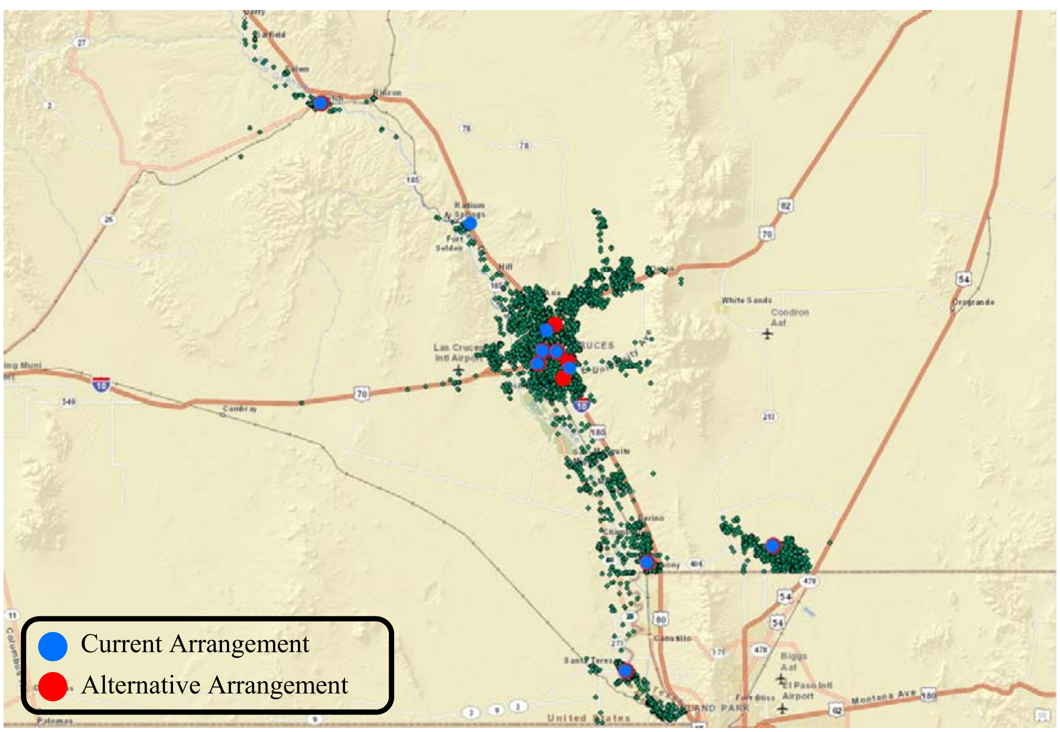


Figure 4-4. Current vs. Alternative System Configurations (June during peak-hours)

4.3 System Configuration during peak-hours from July to December

Next, we talk about the EMS system configuration and its performance for the peak-hours during the months of July through December. The County operates a fleet of 10 ambulances during this time frame. According to the simulation results, with the current setting, neither the Urban nor Suburban areas did not meet the minimum compliance rate of 90%. The proposed system that resulted from our simulation uses 9 ambulances, but it has met the National Standard of 90% fractile for all three service areas (see Table 4-5).

Table 4-5. Performance Comparison (July – December during peak-hours)

System Configuration	# of Ambulances Required	Fractile of RT (%)					Average RT (min)	
		Urban	Suburban	Rural	Overall Average	95% CI	Overall Average	95% CI
$SYS_{current}$	10	81.2	85.83	1	82.73	79.59-85.87	8.25	7.69-8.76
$SYS_{proposed\_best}$	9	93.17	94.63	1	93.63	92.97-93.96	6.45	6.25-6.64
$SYS_{proposed\_10}$	10	95.35	95.47	99.52	95.45	95.09-95.81	5.74	5.63-5.86

In Table 4-6, we show the detailed arrangements of the systems, and they are also depicted on the map in Figure 4-5. Both the current and proposed systems locate five ambulances in the Urban area. However, their locations are slightly different each other. That is, instead of considering the Memorial Medical Center and the South Valles Drive as the site location, the proposed system locates one ambulance at the Wells Street and another at the Missouri Avenue. This change made a positive impact on the improvement of the County's EMS performance at the Urban area as well as Suburban area, which covers Las Cruces, Las Alturas, South Valley, Mesilla, University, La Mesa, Mesquite, and Chamberino. Like the previous case (i.e., the one for peak-hours during the month of June), the proposed system can meet the minimum compliance rate for all three service areas without locating any ambulances at the Radium Springs fire district.

Table 4-6. Three Different System Configurations (July – December during peak-hours)

Site ID	Address	$SYS_{current}$	$SYS_{proposed\_best}$	$SYS_{proposed\_10}$
A	216N Franklin St., Hatch, NM	X	X	X
B	601 Dona Ana School Rd, Las Cruces, NM			
C	6900 Moongate Rd, Las Cruces, NM			
D	2750 Northrise Dr., Las Cruces, NM		X	X
E	5208 Quesenberry Lane, Fairacres, NM			
F	201 E Picacho Ave, Las Cruces, NM	X	X	X
G	151 S Walnut, Las Cruces, NM	X	X	X
H	920 S Valley Dr, Las Cruces, NM	X		X
I	2800 Missouri Ave., Las Cruce,s NM		X	X
J	1510 Wells St, Las Cruces, NM		X	X

K	1 Firehouse Rd., Mesquite, NM			
L	1215 Anthony Dr., Anthony, NM	X	X	X
M	500 E Lisa Dr., Chaparral, NM	X	X	X
N	350 Telles St., Anthony, NM			
O	5650 McNutt Rd., Sunland Park, NM	X	X	X
H1	4311 E Lohman Ave., Las Cruces, NM			
H2	2450 S Telshor Blvd., Las Cruces, NM	X		
H3	2001 N Oregon St., El Paso, TX			
P	1801 Carver Rd., Las Cruces, NM			
Q	1055 E O'Hara Rd., Anthony, NM			
R	183E San Miguel St., La Mesa, NM			
S	5816 Third St., Organ, NM			
T	Harlins St., Rincon, NM			
U	8920 Hwy 187, Garfield, NM			
V	4145 Cholla Rd., Las Cruces, NM			
W	3231N Main St., Las Cruces, NM	X		
X	12212 Leasburg State Park Rd., Radium Springs, NM	X		
	Total number of ambulance vehicles used	10	9	10

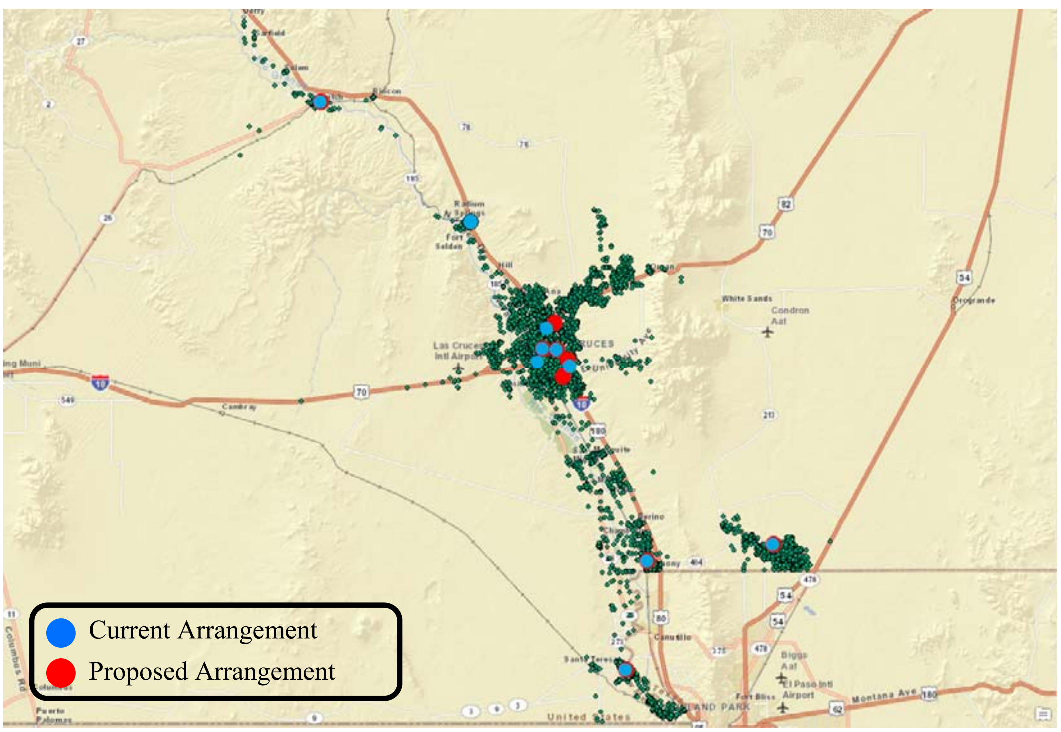


Figure 4-5. Current vs. Proposed System Configurations (July – December during peak-hours)

If the County wants to keep operating 10 ambulances during this time frame, we recommend that they add one ambulance to the Radium Springs fire district or South Valley Drive at the Las Cruces fire district. However, this change may not result in a significant improvement on the system performance. For the purpose of comparison, we provide a system arrangement with 10 ambulances ($SYS_{proposed\_10}$). In this arrangement, we've added one ambulance to Walnut Street, as an example (see Figure 4-6 and Table 4-6). As it can be seen in the table, we observe that there is no significant improvement achieved with this system modification.

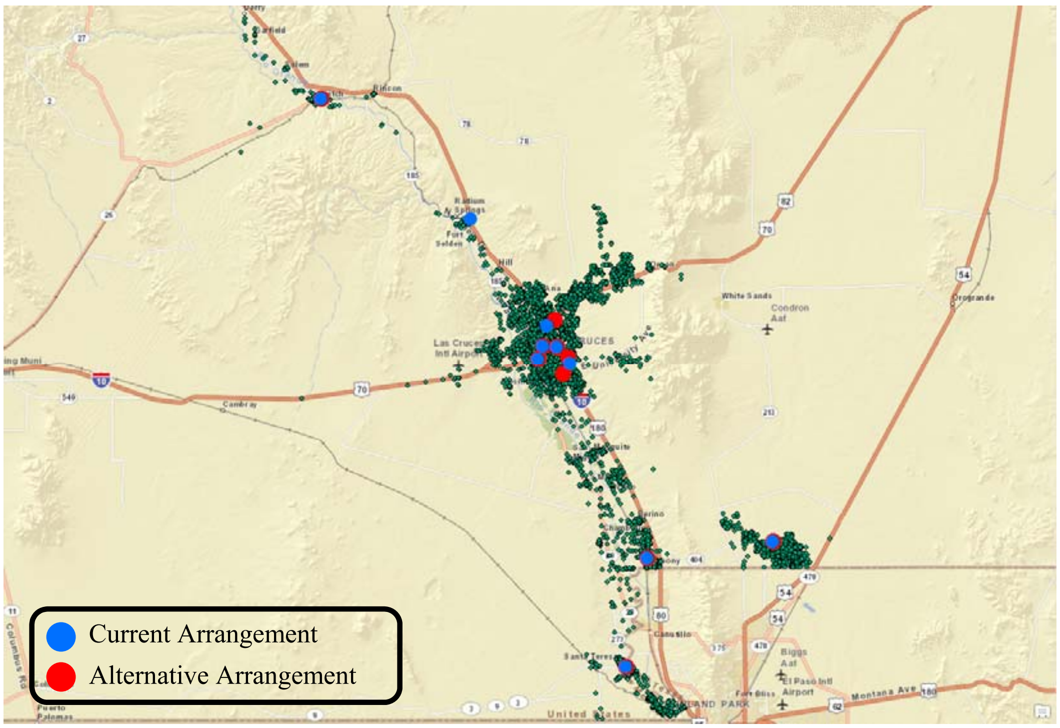


Figure 4-6. Current vs. Alternative System Configurations (July – December during peak-hours)

4.4 System Configuration during nonpeak-hours from January to December

Now we talk about the system configuration for the non-peak hours, i.e., 10pm-10am. The County operates a fleet of seven ambulances for the non-peak hours throughout the whole year, where three of them are located in the City of Las Cruces, and the other four are located in Hatch, Anthony, Chaparral, and Sunland Park, respectively. However, as it can be seen in the Tables 4-7 through 4-9, accordingly to the simulation results, the current system does not satisfy the National Standard RT in the Urban area, where the fractile of RT is around 60%. Even though the minimum compliance rate has been met in the Suburban and Rural areas, due to the poor service in the Urban area, the overall fractile of RT is below 70%. From the Hybrid DES/Heuristic algorithm, we are able to obtain a feasible system configuration which meets the National Standard RT for all three service areas. It is interesting to note that the proposed system arrangement for the non-peak hours are also the same as each other throughout the whole year (see Table 4-10 and Figure 4-7). It operates a fleet of six ambulances. Unlike the current system, it does not locate any ambulances at the Anthony fire district. Also, instead of considering the North Main Street and South Walnut Street as site locations, the proposed system locates one ambulance at the Northrise Drive and another at East Picacho Avenue. This change made a positive impact on the improvement of system performance. As a result, the proposed system can meet the minimum compliance rate at the Urban area as well as Suburban and Rural areas. Note that, in Appendix E, we provide a set of maps showing system configurations with demand clusters.

Table 4-7. Performance Comparison (January – May during nonpeak-hours)

System Configuration	# of Ambulances Required	Fractile of RT (%)					Average RT (min)	
		Urban	Suburban	Rural	Overall Average	95% CI	Overall Average	95% CI
SYS $_{current}$	7	57.13	92.8	98.57	66.4	65.23-67.57	10.72	10.3-11.0
SYS $_{proposed\_best}$	6	91.52	94.28	97.78	92.1	91.64-92.56	6.01	5.86-6.16
SYS $_{proposed\_7}$	7	94.69	94.36	97.98	94.67	93.99-95.35	5.82	5.62-6.03

Table 4-8. Performance Comparison (June during nonpeak-hours)

System Configuration	# of Ambulances Required	Fractile of RT (%)					Average RT (min)	
		Urban	Suburban	Rural	Overall Average	95% CI	Overall Average	95% CI
SYS $_{current}$	7	58.61	93.33	1	67.68	66.74-68.62	9.76	9.45-10.0
SYS $_{proposed\_best}$	6	91.43	94.3	1	92.12	91.54-92.70	5.94	5.78-6.09
SYS $_{proposed\_7}$	7	95.75	95.14	98.48	95.66	95.13-96.19	5.61	5.44-5.78

Table 4-9. Performance Comparison (July – December during nonpeak-hours)

System Configuration	# of Ambulances Required	Fractile of RT (%)					Average RT (min)	
		Urban	Suburban	Rural	Overall Average	95% CI	Overall Average	95% CI
SYS $_{current}$	7	60.95	95.32	99.44	70.09	68.70-71.48	9.47	9.18-9.76
SYS $_{proposed\_best}$	6	92.78	96.59	97.56	93.49	93.06-93.92	5.49	5.38-5.60
SYS $_{proposed\_7}$	7	96.33	95.73	1	96.27	95.53-97.01	5.34	5.07-5.61

If the County wants to keep operating seven ambulances during this time frame, we recommend that they add one ambulance to the Missouri Avenue in the Las Cruces fire district. However, this change may not result in a significant improvement on the system performance. We provide this system configuration and its performance in Table 4-10 and is depicted in Figure 4-8. As it can be seen in the Tables 4-7 through 4-9, we observe no significant improvement on the system performance with this extra ambulance.

Table 4-10. Three Different System Configurations (year-round during nonpeak-hours)

Site ID	Address	$SYS_{current}$	$SYS_{proposed\_best}$	$SYS_{proposed\_7}$
A	216N Franklin St., Hatch, NM	X	X	X
B	601 Dona Ana School Rd, Las Cruces, NM			
C	6900 Moongate Rd, Las Cruces, NM			
D	2750 Northrise Dr., Las Cruces, NM		X	X
E	5208 Quesenberry Lane, Fairacres, NM			
F	201 E Picacho Ave, Las Cruces, NM		X	X
G	151 S Walnut, Las Cruces, NM	X		
H	920 S Valley Dr, Las Cruces, NM	X	X	X
I	2800 Missouri Ave., Las Cruce,s NM			X
J	1510 Wells St, Las Cruces, NM			
K	1 Firehouse Rd., Mesquite, NM			
L	1215 Anthony Dr., Anthony, NM	X		
M	500 E Lisa Dr., Chaparral, NM	X	X	X
N	350 Telles St., Anthony, NM			
O	5650 McNutt Rd., Sunland Park, NM	X	X	X
H1	4311 E Lohman Ave., Las Cruces, NM			
H2	2450 S Telshor Blvd., Las Cruces, NM			
H3	2001 N Oregon St., El Paso, TX			
P	1801 Carver Rd., Las Cruces, NM			
Q	1055 E O'Hara Rd., Anthony, NM			
R	183E San Miguel St., La Mesa, NM			
S	5816 Third St., Organ, NM			
T	Harlins St., Rincon, NM			
U	8920 Hwy 187, Garfield, NM			
V	4145 Cholla Rd., Las Cruces, NM			
W	3231N Main St., Las Cruces, NM	X		
X	12212 Leasburg State Park Rd., Radium Springs, NM			
	Total number of ambulance vehicles used	7	6	7

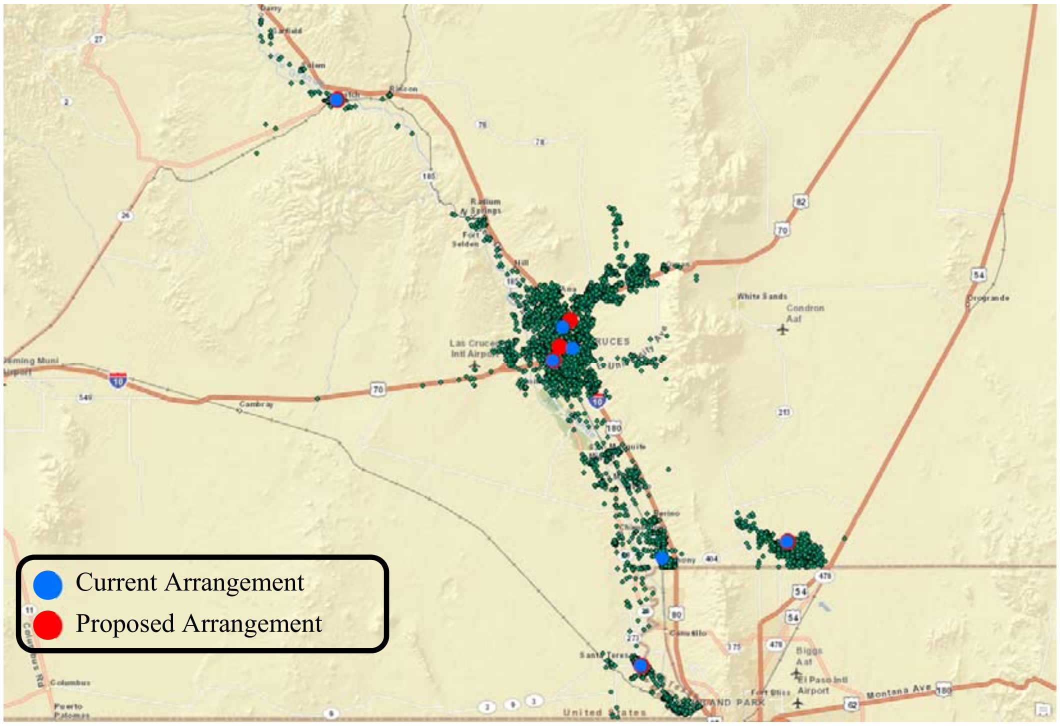


Figure 4-7. Current vs. Proposed System Configurations (year-round during nonpeak-hours)

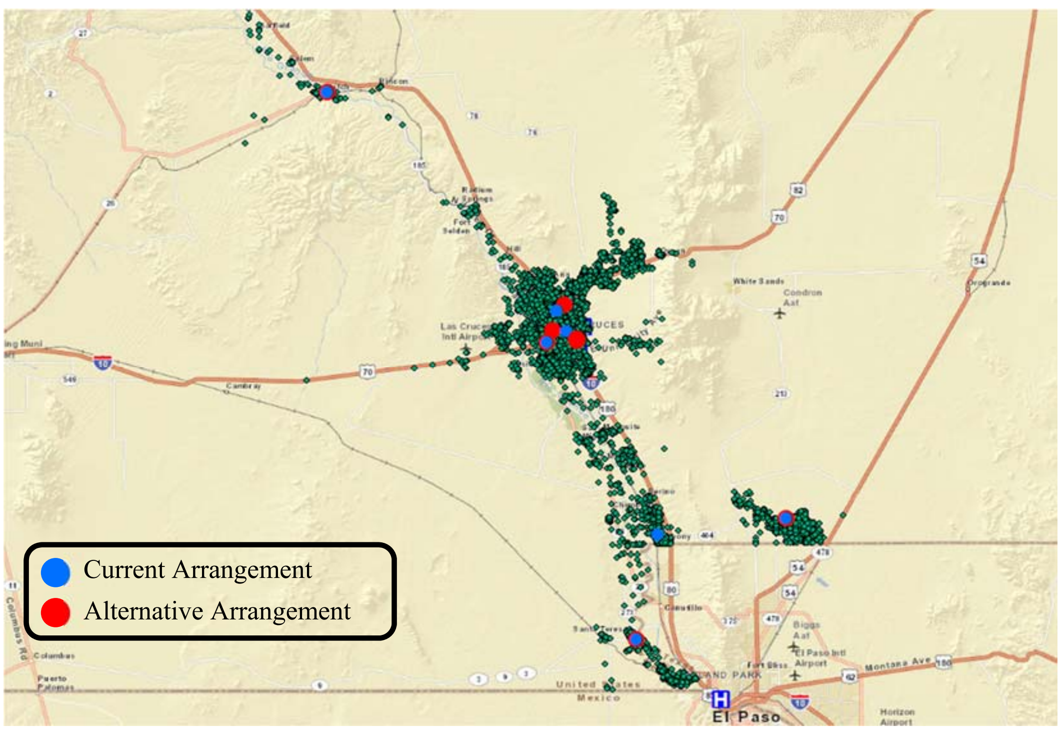


Figure 4-8. Current vs. Alternative System Configurations (year-round during nonpeak-hours)

5. SUMMARY AND RECOMMENDATIONS

Historically, the primary criterion for responsiveness of emergency services is the response time. The ambulance response time at the Dona Ana County is the time interval from the receipt of dispatch to the scene.

- According to the AMR Dona Ana County's ARC Report in December, 2013, the County uses a standard Response Time (RT), which is based on the radius or the distance between the location of the call and the place selected as the center of each ambulance zone.

  Recommendation: It is highly recommended that the County adopts the National Standard RT which was set by the population density of the compliance area. Note that the current research is based on the National Standard RT.

- According to Doña Ana County NM Request for Proposal for Emergency and Non-Emergency Ambulance Transport Services (RFP #07-0040), the County considers two types of reporting categories, i.e., *Code1* and *Code3*. While conducting our research, we used the *Code3* speed ratio of 0.82 since the ambulance responding the *Code3* runs faster than the one for the *Code1*. Note that this ratio was estimated based on the actual data.

There are two general approaches to measuring a response time performance: (1) average value of response time and (2) percent of responses within a defined time limit, i.e., fractile response time. Unlike the average response time, by using the fractile measure, we are able to see how often a benchmark time is achieved.

- In the project report back in 2012, we recommended the usage of fractile response time as a performance measure. We notice that the AMR has been using the fractile measure since then, however, in a somewhat different way. While calculating a fractile measure, the AMR has used the County's Monthly Average RT as a benchmark time, instead of the fixed value of the (National) Standard RT. This might lead to inaccurate response-time reliability since different levels of the response-time reliability can be obtained depending on the choice of the benchmark time.

- The Doña Ana County currently uses a monthly response time compliance rate of 85% within each division as specified in the First Amendment to the Contract between Doña Ana County and American Medical Response (AMR) from contract # 09-015.

  Recommendation: The usage of the compliance with the minimum of a 90 percent standard, which is a National Standard, is recommended. The current research is also based on the 90% fractile of response time.

To understand and predict the EMS request call volumes, we have reviewed the County's 31,614 emergency call records based on different times of the day, different days of the week, and different months of the year. These call records cover the entire Dona Ana County for a 2 year period from January 1, 2012 to December 31, 2013.

- The preliminary views of the call volumes and hourly trend show that 65% of the calls occurred from 10am to 10pm. The descriptive statistics also support this finding. It is also observed that the highest system demand occurred during lunch time (12pm-1pm) with an hourly average of 2.4 calls.

- A weekly peak demand occurs on Friday. However, there are no significant differences on the call volume among the seven days, and this finding is supported by the descriptive statistics.

- It is also observed that relatively high demands occurred from January through May. Note that more than 55% of the calls were generated in the County during these 5 months. We have conducted statistical analysis to test if these patterns are significant. The descriptive statistics show that there are significant differences on the call volumes among three groups, i.e., January through May, June, and July through December.

  Recommendation: While operating ambulances, the entire year needs to be broken down to three distinct periods, namely (1) January through May, (2) June, and (3) July through December. Also, each of the three periods need to be subdivided into two time frames, namely (1) peak hours (10am-10pm) and (2) non-peak hours (10pm-10am). Note that our analysis in this research is also based on the six different time frames.

According to literature surveys, another critical factor for driving response time performance and reliability is an ability to understand and predict call volumes based on geographical locations of calls. Therefore, we reviewed the County's EMS call data based on the geographical call locations.

- About 30% of the data cannot be used for analysis due to the inaccuracy of the data information, i.e., the call locations recorded in the data were not recognizable on the Geographic Information System (GIS) software. It is also noticed that, after the geocoding, we were able to clean the data, i.e., a few call locations were outside the county limits and they were discarded in the analysis. As a result, only 21,507 call records are used for this study.

  Recommendation: It is highly recommended that the County keeps more accurate information about the call location including the street name and zip code. It is of great importance that good qualities of data be recorded. For the future study, therefore, the following information should be included in the database: call location (zip code, street name and number, and fire district); call type (Code1 or Code3); date and times (call, dispatch, en-route, arrival at scene, time when ambulance becomes available, and the response standard time).

The call data was grouped together based on the similarities of their geographical location. The *K-means* clustering algorithm was used to find the partition of emergency call locations such that the distances between the call locations within the same cluster are minimized. As the desired number of clusters for the Dona Ana County's EMS request call data, 18 was selected.

- The algorithm produced 18 centroids for each cluster, where the centroid is a good representation of all the observations within the cluster. Among them, 10 centroids are identified as Urban areas which applies to the Standard response time of 0:08:59. The Urban areas are located in the center of the county, which includes Las Cruces, Fairacres, Mesilla, South Valley, Las Alturas, and University fire districts.

- Only one of them is identified as a Rural area which applies to the Standard RT of 0:20:59. Rincon, Hatch, and Garfield fire districts are included in the Rural area

- The other 7 centroids were classified as Suburban area. Five of them are located in the Southern Doña Ana County (i.e., Mesquite, La Mesa, Chamberino, La Union, Anthony, Chaparral, Santa Teresa, Sunland Park, Far South, and West Valley), and two of them are in the Central Doña Ana County (i.e., Dona Ana, Radium Springs, Organ, and White Sands). These Suburban areas are applied to the Standard response time of 0:15:59. All of this classification information are used for our simulation model.

- The current study includes 27 potential candidate site stations including 3 hospitals, which were identified by the Dona Ana County and AMR. Among them, 4 locations are in Northern Dona Ana County, 15 including 2 hospitals are located in the Central Dona Ana County, and the other 8 locations including 1 hospital are in the Southern Dona Ana County (Note that the hospital is Providence Memorial Hospital which is located in El Paso, Texas).

While conducting the analysis, the analysis periods are broken down to three distinct periods, namely, January through May, June, and July through December, and then these three periods are subdivided into peak hours (10am-10pm) and non-peak hours (10pm-10am). From the hybrid DES/Heuristic algorithm, we have obtained the best system configuration for each of the six different time frames.

- *System Configuration year-round during peak-hours:* During this time frame, the Dona Ana County operates a fleet of 10 ambulance vehicles. According to the simulation results, with the current setting, only the Rural area met the National Standard of 90% fractile. Neither the Urban nor Suburban areas did not meet the minimum compliance rate.

Recommendation for System Configuration during peak-hours from January to May: We recommend operation of 11 ambulances, with which the minimum compliance rate of 90% can be achieved for all three service areas. The proposed EMS systems deploys six ambulances in the Urban area, while the County's current system deploys five (see Table 5-1). That is, instead of locating one ambulance at the Memorial Medical Center, the proposed system locates two ambulances in the southern area of the City of Las Cruces, i.e., one at the Wells Street and another at the Missouri Avenue. Also, the proposed system locates one ambulance in the Dona Ana fire district instead of the Radium Springs fire district, which made the system handle a relatively larger number of EMS calls in the Suburban area (such as Dona Ana, Organ, and Fairacres fire districts), as well as the Urban area (such as Northeast area of the Las Cruces fire district, i.e., the Highway 70 area). If the county has to deploy only ten ambulances, we recommend that the County removes one ambulance from the Anthony fire district (see Table 5-1). However, the Suburban area won't meet the National Standard RT with this change.

Recommendation for System Configuration during peak-hours in June: We recommend operation of 9 ambulances (see Table 5-1). Even though the proposed system operates only 9 ambulance vehicles, it satisfies the minimum compliance rate for all three service areas. Instead of considering the Memorial Medical Center and the South Walnut Street as site locations, the proposed system locates one ambulance at Wells Street and another at Missouri Avenue. The proposed system does not locate any ambulances at the Radium Springs, however, it can still meet the minimum compliance rate for all three service areas. If the County wants to keep operating 10 ambulances during this time frame, we recommend the addition of one ambulance to the Radium Springs fire district or the South Walnut Street in the Las Cruces fire district. However, with this extra ambulance, we may not expect a significant improvement on the system performance.

Recommendation for System Configuration during peak-hours from July to December: We recommend operation of 9 ambulances. Even though the proposed system operates only 9 ambulance vehicles, it satisfies the minimum compliance rate for all three service areas. Instead of considering the Memorial Medical Center and the South Valles Drive as the site location, the proposed system locates one ambulance at the Wells Street and another at the Missouri Avenue. The proposed system can meet the minimum compliance rate for all three service areas without locating any ambulances at the Radium Springs fire district. If the County wants to keep operating 10 ambulances during this time frame, we recommend the addition of one ambulance to the Radium Springs fire district or the South Valley Drive in the Las Cruces fire district. However, with this extra ambulance, we may not expect a significant improvement on the system performance.

- *System Configuration year-round during nonpeak-hours:* The County operates a fleet of seven ambulances for the non-peak hours throughout the whole year, where three of them are located in the City of Las Cruces, and the other four are located in Hatch, Anthony, Chaparral, and Sunland Park, respectively. According to the simulation results, the current system does not satisfy the National Standard RT in the Urban area, where the fractile of RT is around 60%.

  Recommendation for System Configuration year-round during nonpeak-hours: We recommend operation of 6 ambulances (see Table 5-2). Even though the proposed system operates only 6 ambulance vehicles, it satisfies the minimum compliance rate for all three service areas. It is interesting to note that the proposed system arrangement for the non-peak hours are also the same as each other throughout the whole year. Unlike the current system, it does not locate any ambulances at the Anthony fire district. Also, instead of considering the North Main Street and South Walnut Street as site locations, the proposed system locates one ambulance at the Northrise Drive and another at East Picacho Avenue. If the County wants to keep operating seven ambulances during this time frame, we recommend that they add one ambulance to the Missouri Avenue in the Las Cruces fire district. However, this change may not result in a significant improvement on the system performance.

Table 5-1 Detailed System Arrangement during the Peak-hours

Site ID	Address	Current	Proposed (Jan-May)	Proposed (Jun)	Proposed (Jul-Dec)
A	216N Franklin St., Hatch, NM	X	X	X	X
B	601 Dona Ana School Rd, Las Cruces, NM		X		
C	6900 Moongate Rd, Las Cruces, NM				
D	2750 Northrise Dr., Las Cruces, NM		X	X	X
E	5208 Quesenberry Lane, Fairacres, NM				
F	201 E Picacho Ave, Las Cruces, NM	X	X	X	X
G	151 S Walnut, Las Cruces, NM	X	X		X
H	920 S Valley Dr, Las Cruces, NM	X	X	X	
I	2800 Missouri Ave., Las Cruce,s NM		X	X	X
J	1510 Wells St, Las Cruces, NM		X	X	X
K	1 Firehouse Rd., Mesquite, NM				
L	1215 Anthony Dr., Anthony, NM	X	(X)	X	X
M	500 E Lisa Dr., Chaparral, NM	X	X	X	X
N	350 Telles St., Anthony, NM				
O	5650 McNutt Rd., Sunland Park, NM	X	X	X	X
H1	4311 E Lohman Ave., Las Cruces, NM				
H2	2450 S Telshor Blvd., Las Cruces, NM	X			
H3	2001 N Oregon St., El Paso, TX				
P	1801 Carver Rd., Las Cruces, NM				

Q	1055 E O'Hara Rd., Anthony, NM				
R	183E San Miguel St., La Mesa, NM				
S	5816 Third St., Organ, NM				
T	Harlins St., Rincon, NM				
U	8920 Hwy 187, Garfield, NM				
V	4145 Cholla Rd., Las Cruces, NM				
W	3231N Main St., Las Cruces, NM	X			
X	12212 Leasburg State Park Rd., Radium Springs, NM	X			
	Total number of ambulance vehicles used	10	11(10)	9	9

Table 5-2 Detailed System Arrangement during the Nonpeak-hours

Site ID	Address	Current	Proposed
A	216N Franklin St., Hatch, NM	X	X
B	601 Dona Ana School Rd, Las Cruces, NM		
C	6900 Moongate Rd, Las Cruces, NM		
D	2750 Northrise Dr., Las Cruces, NM		X
E	5208 Quesenberry Lane, Fairacres, NM		
F	201 E Picacho Ave, Las Cruces, NM		X
G	151 S Walnut, Las Cruces, NM	X	
H	920 S Valley Dr, Las Cruces, NM	X	X
I	2800 Missouri Ave., Las Cruce,s NM		
J	1510 Wells St, Las Cruces, NM		
K	1 Firehouse Rd., Mesquite, NM		
L	1215 Anthony Dr., Anthony, NM	X	
M	500 E Lisa Dr., Chaparral, NM	X	X
N	350 Telles St., Anthony, NM		
O	5650 McNutt Rd., Sunland Park, NM	X	X
H1	4311 E Lohman Ave., Las Cruces, NM		
H2	2450 S Telshor Blvd., Las Cruces, NM		
H3	2001 N Oregon St., El Paso, TX		
P	1801 Carver Rd., Las Cruces, NM		
Q	1055 E O'Hara Rd., Anthony, NM		
R	183E San Miguel St., La Mesa, NM		
S	5816 Third St., Organ, NM		
T	Harlins St., Rincon, NM		
U	8920 Hwy 187, Garfield, NM		
V	4145 Cholla Rd., Las Cruces, NM		
W	3231N Main St., Las Cruces, NM	X	
X	12212 Leasburg State Park Rd., Radium Springs, NM		
	Total number of ambulance vehicles used	7	6

- Since 1990s, some EMS providers have implemented a co-responder strategy in an attempt to reduce the EMS operating costs while maintaining good system reliability. According to the AAA, however, it has no significant impacts on the performance of the EMS system, especially in Urban and Suburban areas. Compared to the Urban and Suburban areas, rural areas are characterized by large geographic coverage areas. The EMS request call volumes are relatively low due to small population density. The rural areas are also characterized by long travel distance.

  Recommendation: According to literature survey, residents in the Rural area experience higher injury and death rates from trauma. If the County implements the co-responder strategy to the Rural area, Rural patients' satisfaction level will be improved. However, we recommend that statistical analysis needs to be conducted if the co-responder strategy has a positive impact on the EMS system reliability. This will help dynamic ambulance deployment to match the service demands more accurately. However, to conduct the statistical analysis, the County has to keep more accurate information about the needs of the patient and clinical outcomes, as well.

Appendix A.

Non-parametric test for grouping the EMS request call data

Table A1. Month of the year (January through May)

Month	N	Median	Ave Rank	Z
1	31	55.00	67.1	-1.27
2	28	55.50	72.9	-0.41
3	31	56.00	76.5	0.07
4	30	57.00	84.3	1.15
5	31	57.00	79.2	0.46
Overall	151		76.0	

H = 2.66 DF = 4 P = 0.617
H = 2.66 DF = 4 P = 0.616 (adj for ties)

Table A2. Month of the year (June)

Month	N	Median	Ave Rank	Z
6	30	32.50	131.3	2.27
7	31	27.00	82.6	-2.42
8	31	29.00	103.2	-0.42
9	30	32.00	125.1	1.68
10	31	29.00	96.0	-1.12
11	30	30.00	107.2	-0.03
12	31	30.00	108.5	0.10
Overall	214		107.5	

H = 13.12 DF = 6 P = 0.041
H = 13.15 DF = 6 P = 0.041 (adj for ties)

Table A3. Month of the year (July through December)

Month	N	Median	Ave Rank	Z
7	31	27.00	73.2	-2.21
8	31	29.00	92.1	-0.04
9	30	32.00	112.2	2.21
10	31	29.00	85.5	-0.80
11	30	30.00	95.7	0.36
12	31	30.00	97.0	0.51
Overall	184		92.5	

H = 9.03 DF = 5 P = 0.108
H = 9.06 DF = 5 P = 0.107 (adj for ties)

Table A4. Days of the week (Monday through Sunday)

DOW	N	Median	Ave Rank	Z
Friday	52	42.00	201.9	1.39
Monday	52	38.00	186.7	0.28
Saturday	52	36.00	178.5	-0.33
Sunday	52	35.00	173.5	-0.70
Thursday	52	38.50	174.5	-0.63
Tuesday	53	37.00	187.5	0.34
Wednesday	52	34.50	178.3	-0.35
Overall	365		183.0	

H = 2.79 DF = 6 P = 0.835
H = 2.79 DF = 6 P = 0.834 (adj for ties)

Table A5. Times of the day (Peak hours, i.e., 10am-10pm)

2-hour period	N	Median	Ave Rank	Z
10-12	365	4.000	1079.5	-0.53
12-14	365	4.000	1119.3	0.79
14-16	365	4.000	1127.7	1.07
16-18	365	4.000	1144.1	1.61
18-20	365	4.000	1071.9	-0.78
20-22	365	4.000	1030.5	-2.15
Overall	2190		1095.5	

H = 8.22 DF = 5 P = 0.144
H = 8.35 DF = 5 P = 0.138 (adj for ties)

Appendix B.

Classification of the 18 centroids based on population density

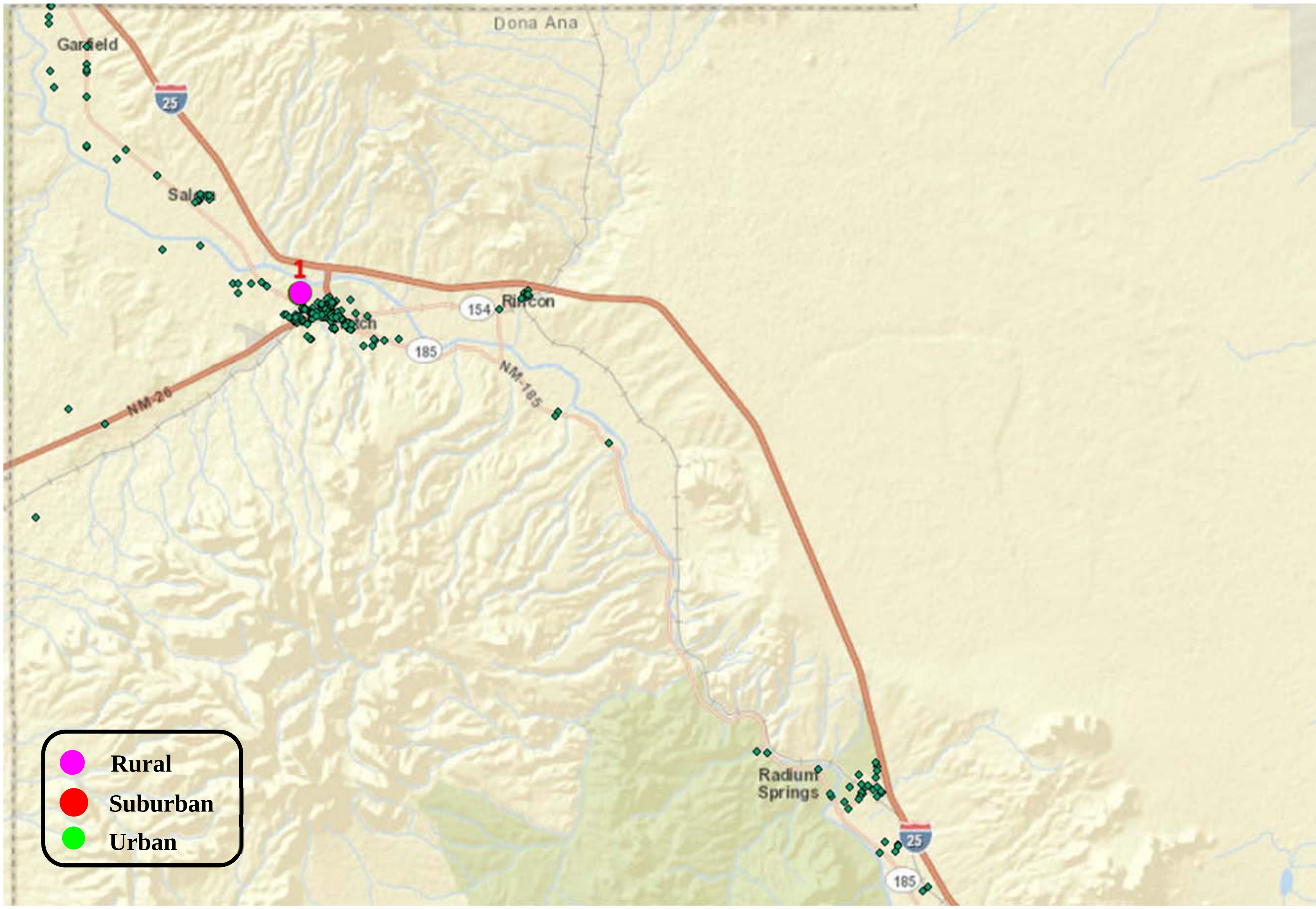


Figure B1. Classification of the 18 centroids based on population density (Northern Dona Ana County)

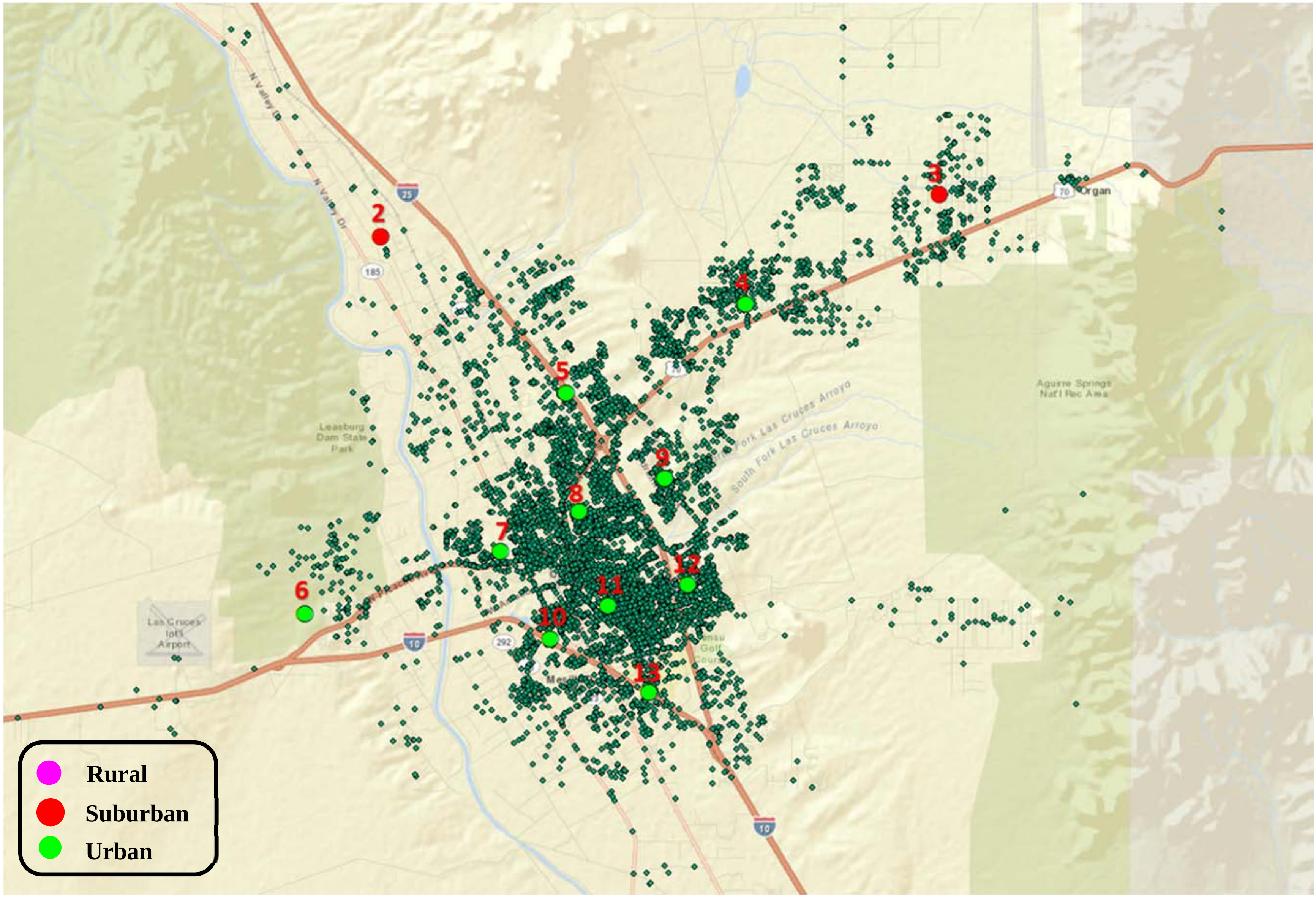


Figure B2. Classification of the 18 centroids based on population density (Central Dona Ana County)

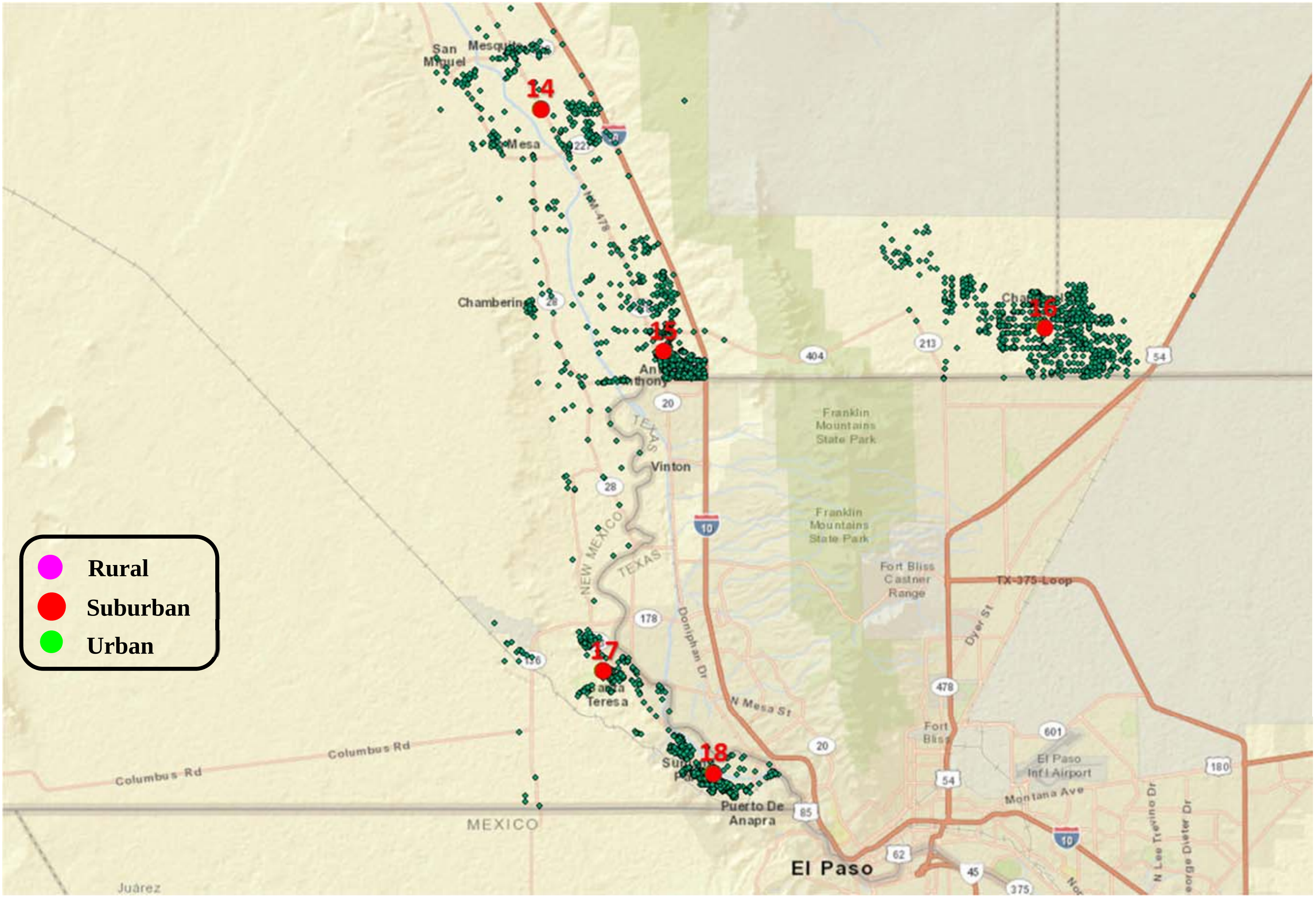


Figure B3. Classification of the 18 centroids based on population density (Southern Dona Ana County)

Appendix C.

Initial 27 candidate site locations including three hospitals

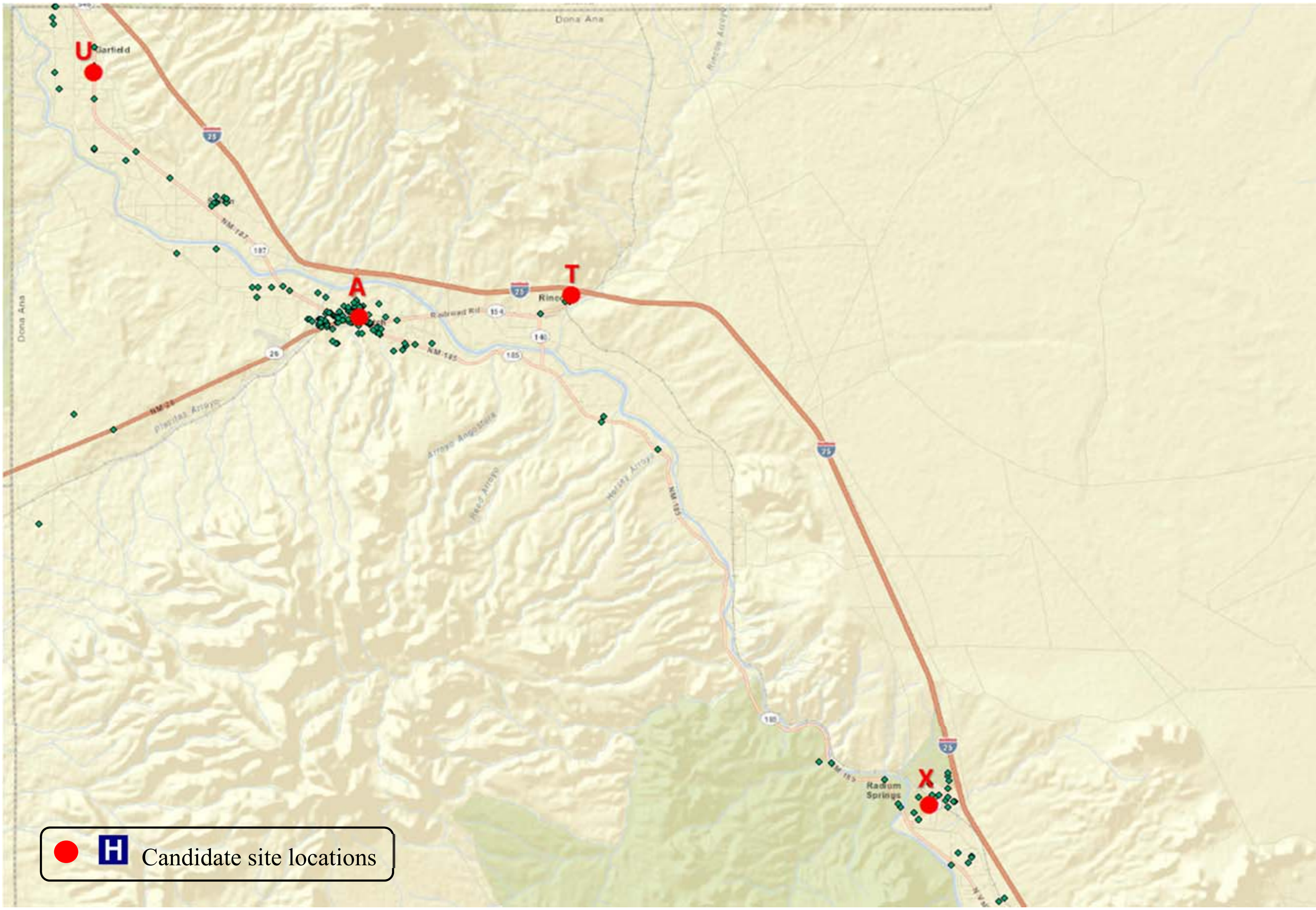


Figure C1. Initial 27 candidate site locations including three hospitals (Northern Dona Ana County)

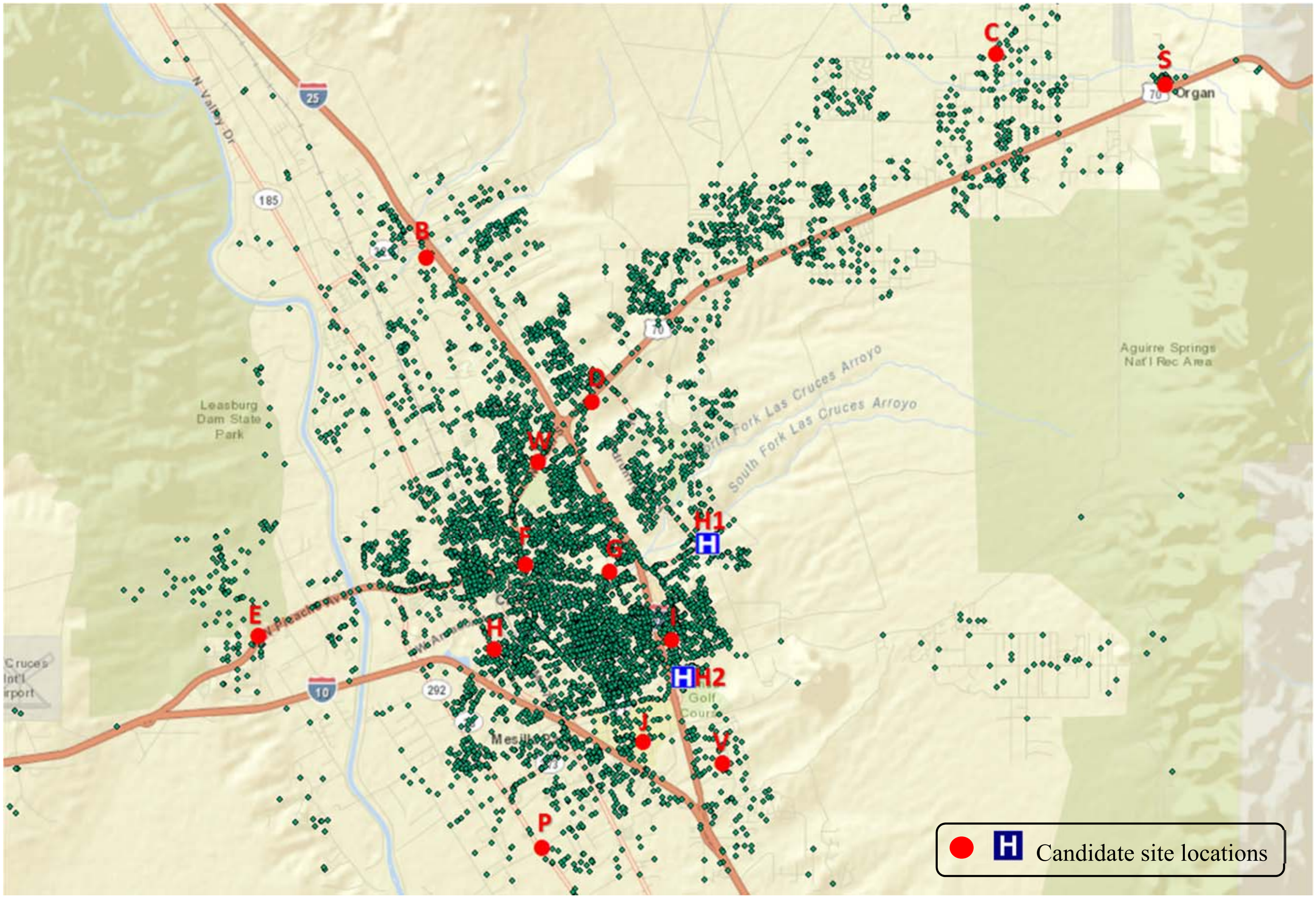


Figure C2. Initial 27 candidate site locations including three hospitals (Central Dona Ana County)

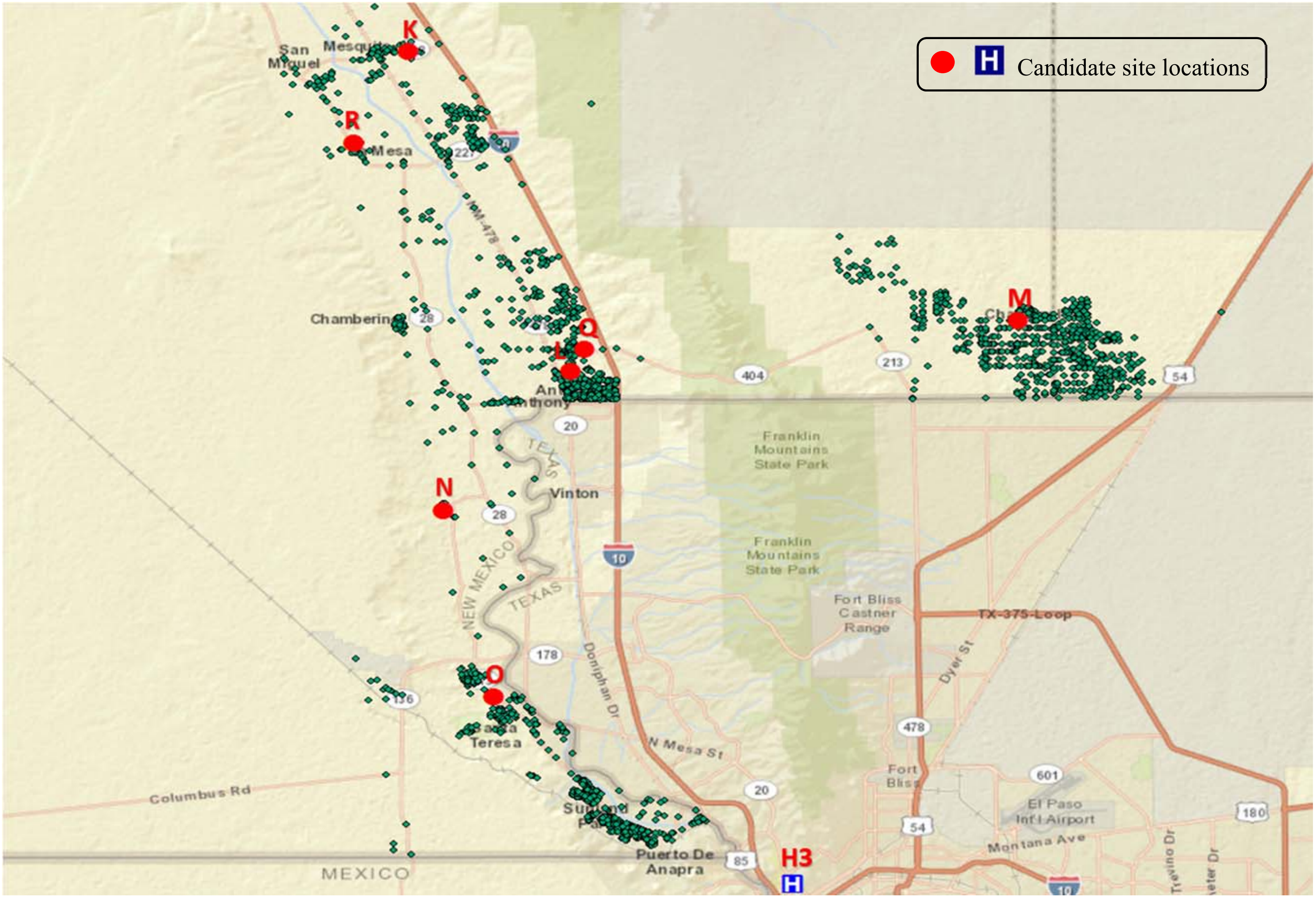


Figure C3. Initial 27 candidate site locations including three hospitals (Southern Dona Ana County)

Appendix D.

Probability Distributions and Their Parameter Values used in the Simulation Model

Table D1. Inter-Arrival Rates (λ) of EMS Request Calls

Time	Code3 (Jan-May)	Code1 (Jan-May)	Code3 (June)	Code1 (June)	Code3 (Jul-Dec)	Code1 (Jul-Dec)
00:00-02:00	0.3063	0.5050	0.2000	0.3583	0.1963	0.2850
02:00-04:00	0.2136	0.3775	0.1083	0.2917	0.1145	0.2173
04:00-06:00	0.2202	0.2980	0.1250	0.1833	0.1250	0.1542
06:00-08:00	0.4007	0.3146	0.2417	0.2167	0.2699	0.2243
08:00-10:00	0.6656	0.5497	0.3833	0.4083	0.3481	0.3551
10:00-12:00	0.8013	0.7119	0.5000	0.5583	0.4019	0.4042
12:00-14:00	0.8311	0.7053	0.6417	0.6083	0.4603	0.4182
14:00-16:00	0.8129	0.7368	0.4667	0.4083	0.4404	0.4171
16:00-18:00	0.8195	0.7881	0.4833	0.5417	0.4264	0.4276
18:00-20:00	0.6639	0.8791	0.4333	0.5917	0.3458	0.4252
20:00-22:00	0.5844	0.7699	0.5000	0.7000	0.3516	0.4685
22:00-24:00	0.4205	0.5993	0.2667	0.5250	0.2079	0.3773

Table D2. Probability Distributions used for Each Random Process in the Simulation Model

Process	Distribution	Parameters	Squared Error	Chi Square Test Statistic	Decision
Call Process Time	Gamma (alpha, beta)	(3.16,0.426)	0.000225	0.371	Good Fit
Time to Dispatch	Empirical	(.20,0.013,.4,0.058,.6,0.140,.8,0.272,1,0.414,1.2,0.574,1.4,0.705,1.6,0.814,1.8,0.899,2,0.959,2.2,1)			
Time with Patient	Gamma (alpha, beta)	(4.29 , 3.45)	0.001495	0.212	Good Fit
Time in Hospital	Empirical	(2.740,0.016,5.481, 0.022,8.221, 0.026,10.962, 0.041,13.703,0.092,16.444,0.171,19.184,0.292,21.925,0.482, 24.666, 0.647, 27.407,0.744,30.148,0.829,32.888,0.882,35.629,0.922,38.370,0.936,41.111,0.963,43.851,0.968,46.592, 0.980, 49.333, 0.984,52.074,0.989, 54.815,0.992,57.555,0.995,60.296,0.996,63.037,0.997,65.778, 0.997,68.518,0.999,71.259, 0.999,74,1)			

Appendix E.

System Configurations with Demand Clusters

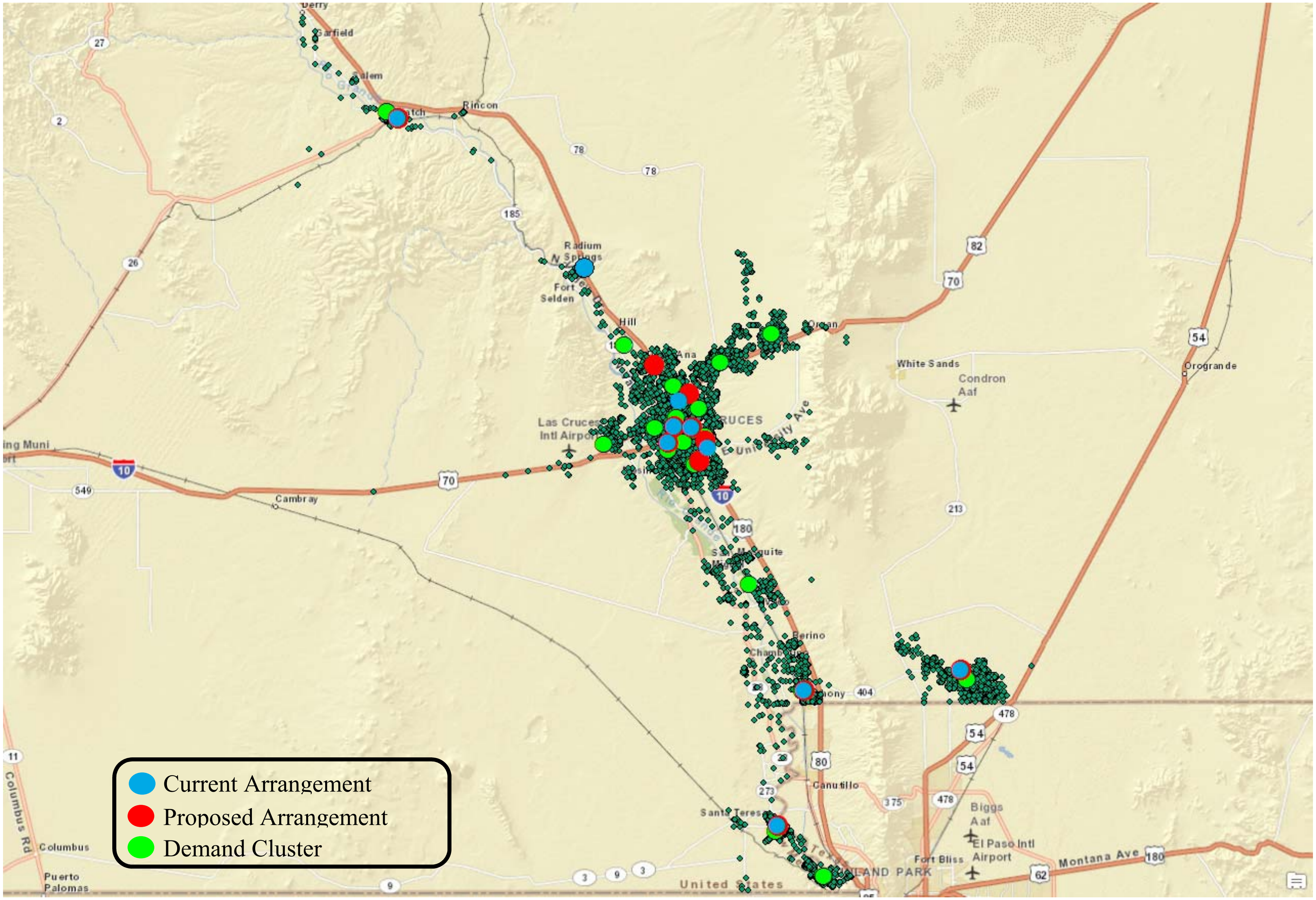


Figure E1. System Configurations with Demand Clusters (January – May during peak-hours)

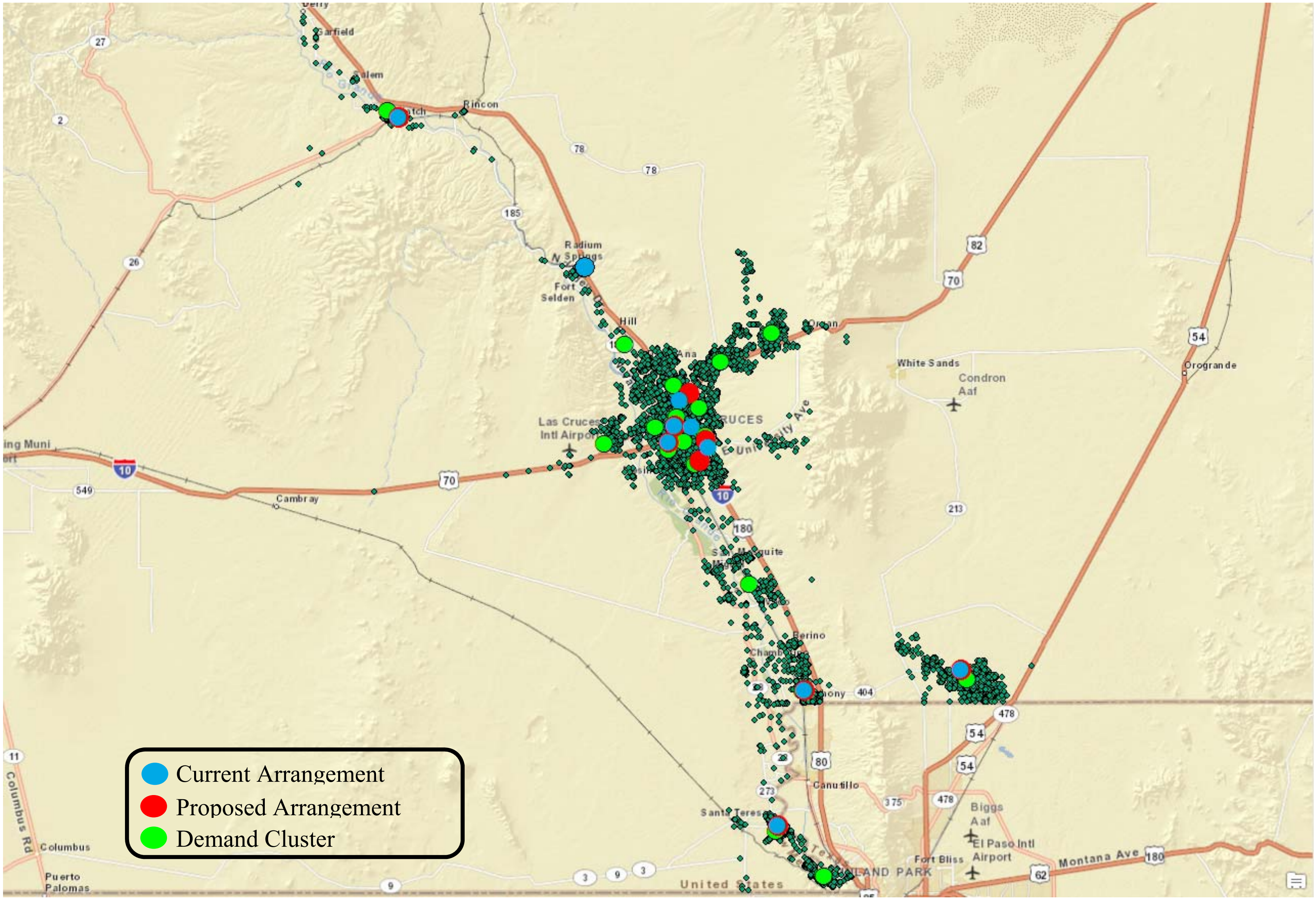


Figure E2. System Configurations with Demand Clusters (June during peak-hours)

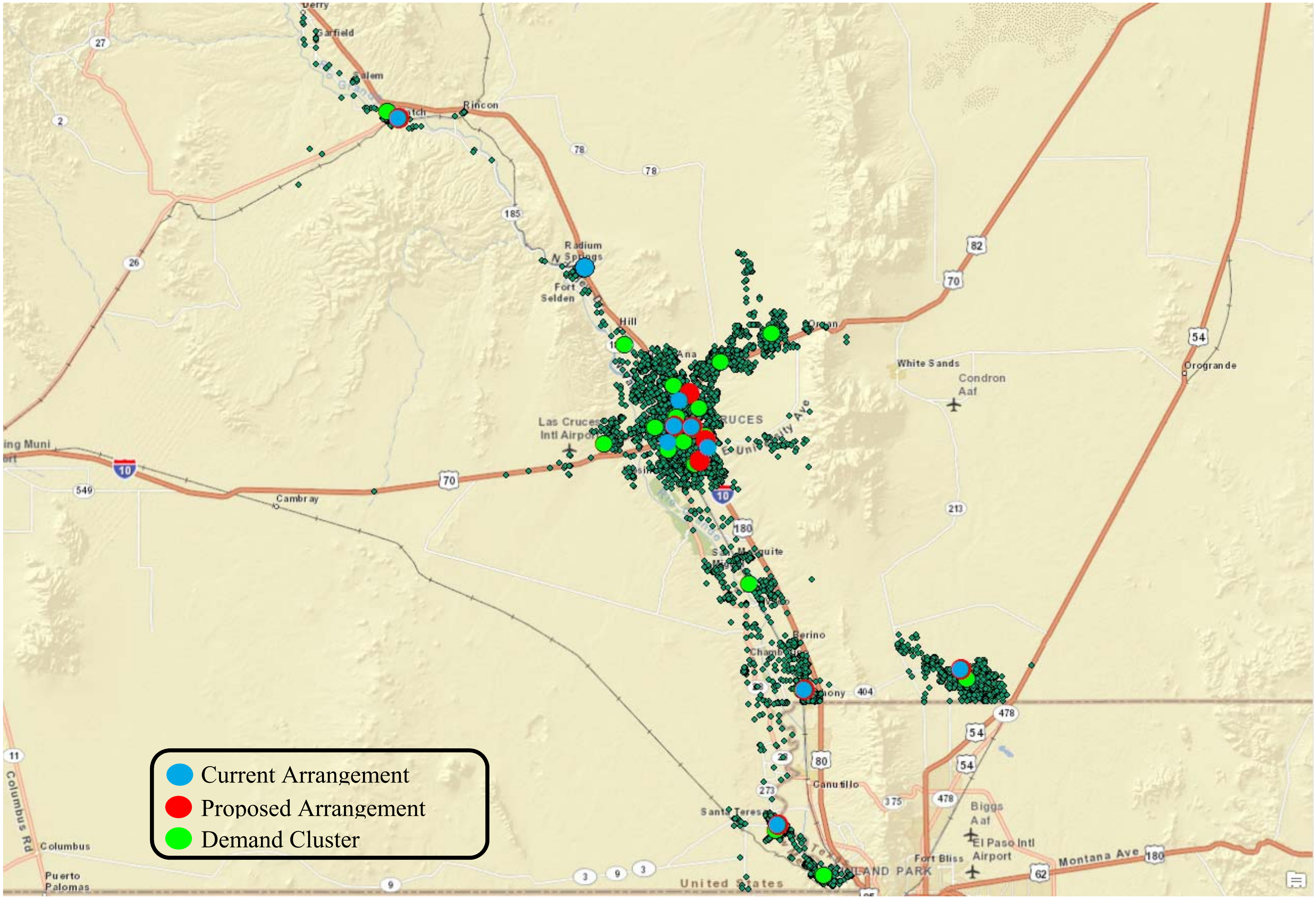


Figure E3. System Configurations with Demand Clusters (July – December during peak-hours)

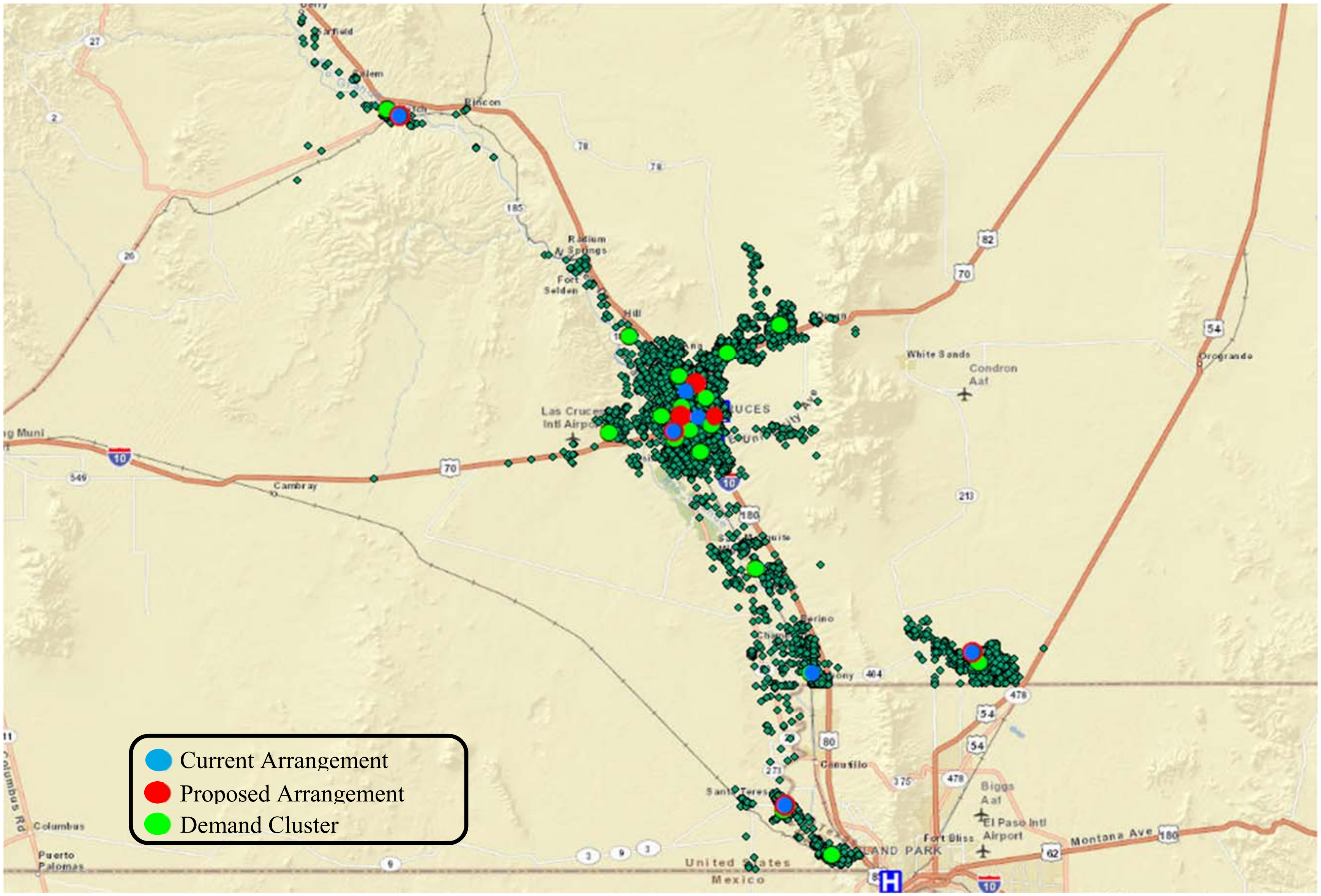


Figure E4. System Configurations with Demand Clusters (year-round during nonpeak-hours)

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