Supplementary Appendix
Optimizing public defibrillator deployment to overcome spatial and temporal accessibility barriers

Short title: Optimizing spatiotemporal AED access

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Section 1.1. Data collection assumptions

Temporal accessibility information (i.e., hours of operation) was not readily available for some of the registered AED sites and candidate AED locations considered in this study. For locations without temporal information online, and that were not reachable by phone or email, or that belonged to a location type with too many constituent sites to individually visit all of them, we estimated their hours of operation as described below.

Registered AEDs

Hours of operation could not be confirmed for 59 of the 737 (8%) of the AED locations by online search, phone, or in-person visit. For those 59 locations, we assumed the following: individual offices, schools, and manufacturing facilities were open 8:00am – 5:00pm, and large condominiums and office towers were open 24 hours a day. The latter assumption is based on the fact that most of those sites have a concierge or security officer present throughout the day and night.

Candidate Locations for New AEDs

Hours of operation could not be confirmed for 1094 of the 4898 (22%) of the candidate locations. For each location type, we assumed hours of operation based on the hours of 20 randomly sampled locations, obtained via phone call. The resulting assumed hours: Childcare centers were open from 7:30am – 6:00pm, English Catholic schools were open from 8:00am – 5:00pm, and ATMs not located within a branch were open 24 hours a day.

Section 1.2. Spatiotemporal optimization model formulation and methodology

The formal description of the spatiotemporal optimization model we used is given below.

- z_{is} is a binary variable indicating whether cardiac arrest *i* is covered during time period *s*
- x_j is a binary variable indicating whether an AED is placed in location *j*

- a_{ijs} is a binary data parameter that indicates whether cardiac arrest *i* is coverable by location *j* during time period *s* (i.e., within 100 meters and occurring during a time when location *j* is open)
- N is the number of locations in which AEDs are placed
- J is the number of candidate locations in which to place AEDs
- I is the number of cardiac arrests in the “training set”
- S is the number of 30 minute time periods during one week

Maximize $\sum_{i=1}^{I}\sum_{s=1}^{S} z_{is}$

Subject to $\sum_{j=1}^{J} x_j \leq N$

$z_{is} \leq \sum_{j=1}^{J} a_{ijs}x_j$, for all $i = 1, \dots, I, s = 1, \dots, S$

$z_{is} \in \{0,1\}$, for all $i = 1, \dots, I, s = 1, \dots, S$

$x_j \in \{0,1\}$, for all $j = 1, \dots, J$

The spatiotemporal optimization model significantly extends the capability of a previous spatial-only model[1] by including temporal information. In particular, the spatiotemporal model partitions the week into 336 30-minute time periods (*S*) and considers both the accessibility (i.e., opening hours) of the candidate locations in 30-minute increments and the time of the OHCA incident.

The spatiotemporal model takes the following inputs:
- **Candidate AED locations:** Locations (Universal Transverse Mercator or Latitude-Longitude coordinates) and hours of operations (hh:mm - hh:mm) of buildings/businesses/points of interest to be considered
- **Historical OHCAs:** Locations (Universal Transverse Mercator or Latitude-Longitude coordinates) and time of OHCA incident (hh:mm:ss)
- **Registered/existing AED locations:** Locations (Universal Transverse Mercator or Latitude-Longitude coordinates) and hours of operations (hh:mm - hh:mm) of buildings/businesses/points of interest that house registered/existing AEDs
- **Model Parameter *N*:** The user-defined number of candidate locations where AEDs are to be placed

Note that the registered/existing AED location data set is not a required input for the model. However, having this data available is useful to ensure that the measurement of *actual coverage* of prospectively placed AEDs accounts for the existing AED infrastructure.

The model outputs are:
- **Selected locations for AED deployment:** The top *N* locations (Universal Transverse Mercator or Latitude-Longitude coordinates) that together maximize *actual coverage* of training set OHCAs
- **Covered OHCAs:** The set of OHCAs covered by the selected candidate AED locations

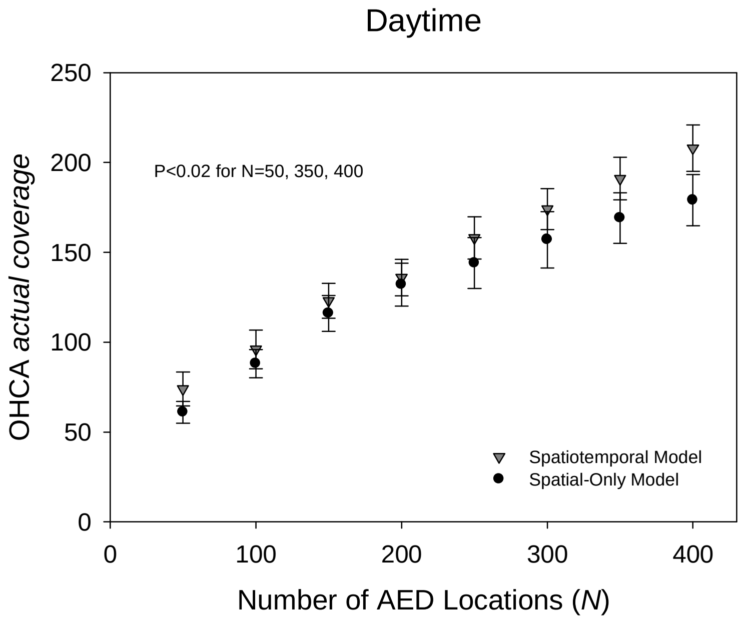
Evaluation of model output:
- ***Actual coverage* of testing set (out-of-sample) OHCAs:** The *actual coverage* of testing set OHCAs, summed over all folds, by the *N* AED locations identified by the model

Section 2. Supplemental Results

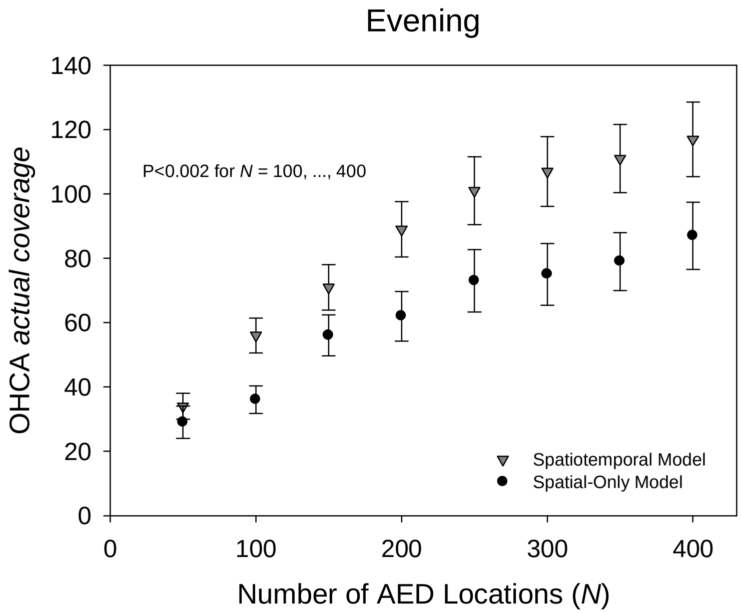
Section 2.1. Analysis 2: Actual coverage of OHCAs by prospective AED locations determined by the spatiotemporal and spatial-only models

The increase in *actual coverage* on testing set OHCAs due to the spatiotemporal model over the spatial-only model was further examined by different times of day (daytime, evening, night), days of the week (weekdays and weekends), and geographies (downtown and outside downtown). Significance of the difference was determined using McNemar’s test for all values of *N* with P<0.05 being significant. The following figures break down the results from Figure 3 in the body of the paper into the above mentioned subcategories.

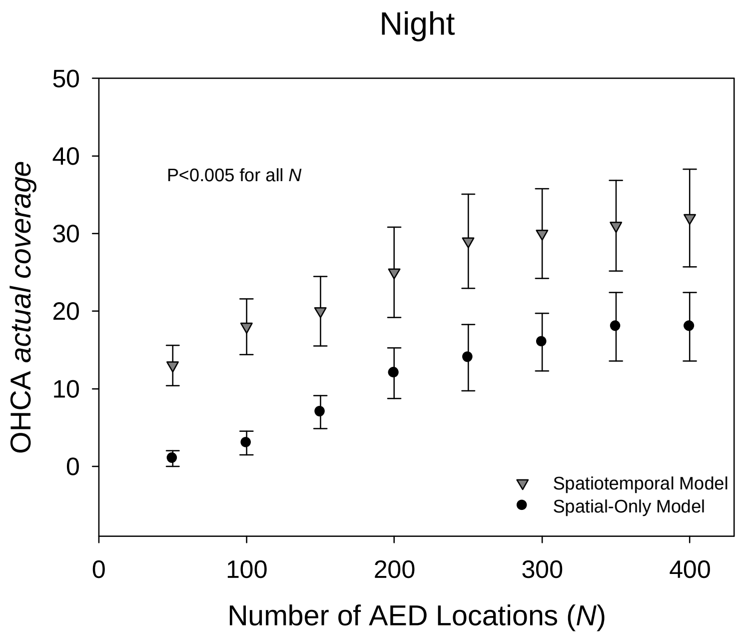
Time of day



Online Figure 1. A*ctual coverage* of testing set OHCAs by prospective AED locations determined by the spatiotemporal and spatial-only models during the daytime (8:00AM – 3:59PM). The difference in a*ctual coverage* was statistically significant for *N* = 50, 350, and 400 (McNemar, P<0.02).

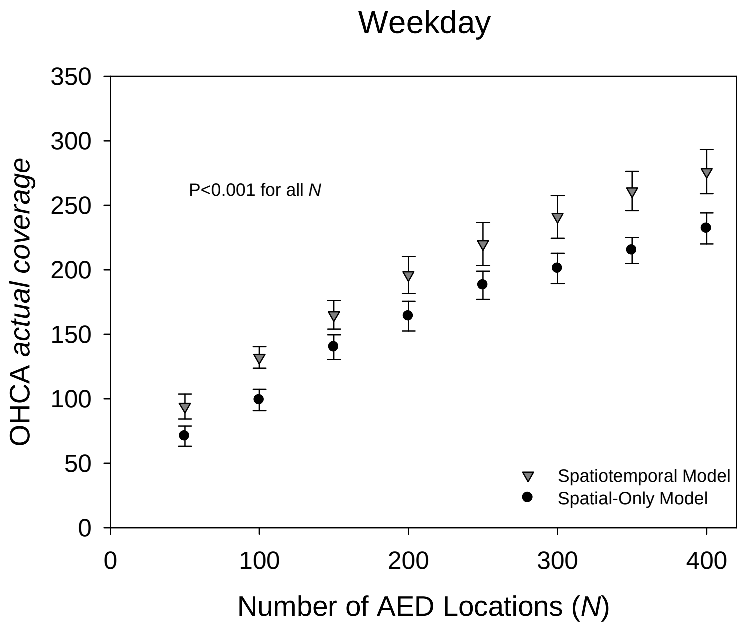


Online Figure 2. A*ctual coverage* of testing set OHCAs by prospective AED locations determined by the spatiotemporal and spatial-only models during the evening (4:00PM – 11:59PM). The difference in a*ctual coverage* was statistically significant for *N* = 100, …, 400 (McNemar, P<0.002).

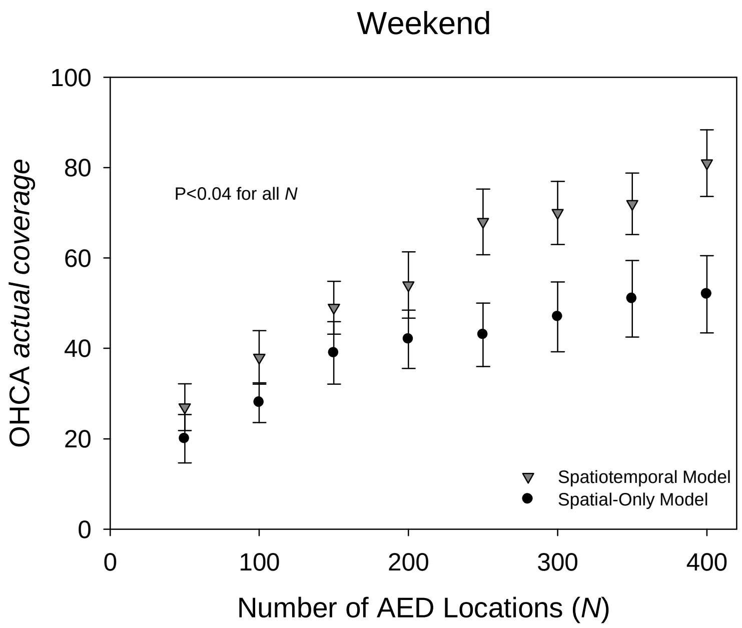


Online Figure 3. A*ctual coverage* of testing set OHCAs by prospective AED locations determined by the spatiotemporal and spatial-only models during the night (12:00AM – 7:59AM). The difference in a*ctual coverage* was statistically significant for all *N* (McNemar, P<0.005).

Day of Week

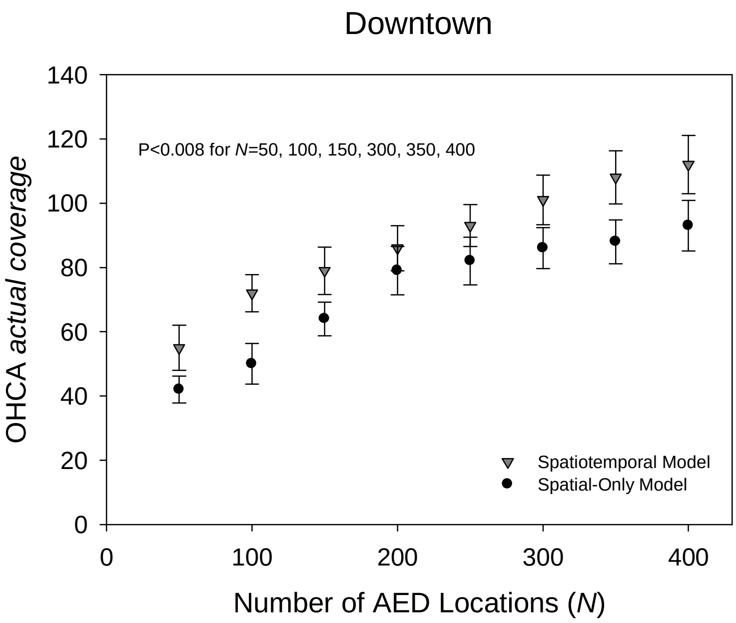


Online Figure 4. A*ctual coverage* of testing set OHCAs by prospective AED locations determined by the spatiotemporal and spatial-only models during the weekdays. The difference in a*ctual coverage* was statistically significant for all *N* (McNemar, P<0.001).

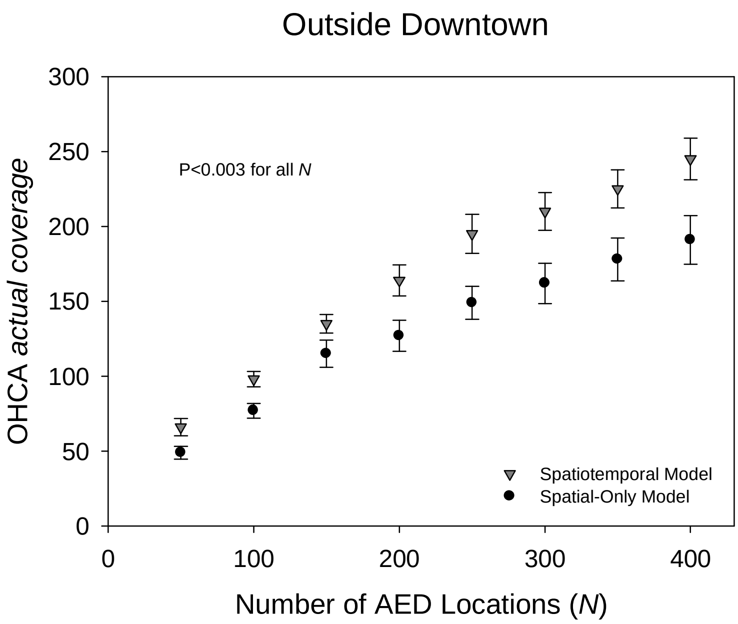


Online Figure 5. A*ctual coverage* of testing set OHCAs by prospective AED locations determined by the spatiotemporal and spatial-only models during the weekend. The difference in a*ctual coverage* was statistically significant for all *N* (McNemar, P<0.04).

Geography



Online Figure 6. A*ctual coverage* of testing set OHCAs by prospective AED locations determined by the spatiotemporal and spatial-only models in downtown. The difference in a*ctual coverage* was statistically significant for *N* = 50, 100, 150, 300, 350, and 400 (McNemar, P<0.008).



Online Figure 7. A*ctual coverage* of testing set OHCAs by prospective AED locations determined by the spatiotemporal and spatial-only models outside downtown. The difference in a*ctual coverage* was statistically significant for all *N* (McNemar, P<0.003).

Section 2.2. Analysis 2: AED placement efficiency of the spatiotemporal model

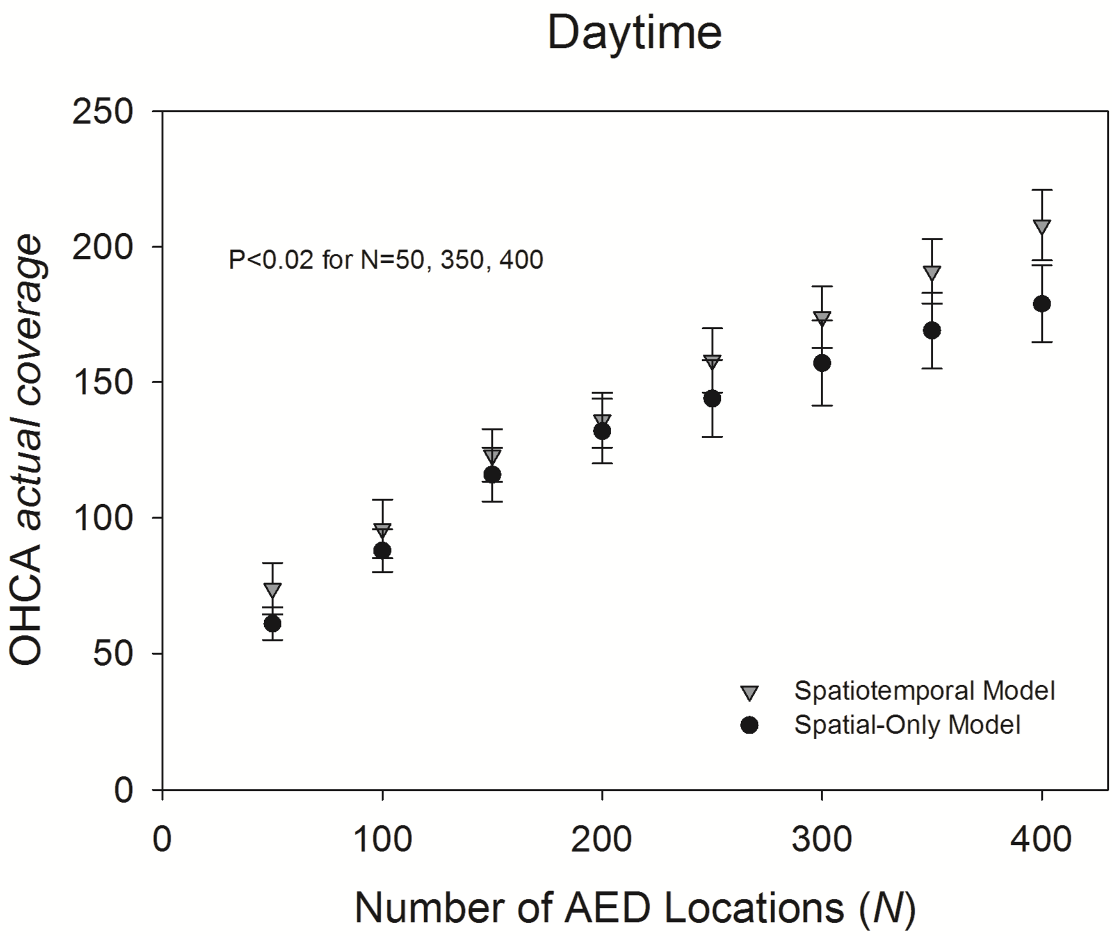
An alternative to measuring the coverage gain of the spatiotemporal model over the spatial-only model (i.e., how much extra coverage is possible with the same number of AED locations) is to measure the “efficiency gain” of the spatiotemporal model in providing the same level of coverage as the spatial-only model (i.e., how many fewer AED locations are needed to provide the same coverage). We computed the number of AED locations required to cover 50, 100, …, 250 testing set OHCAs using the spatiotemporal and spatial-only models. We did not consider coverage levels of 300 or greater, because 300 is an upper limit on possible OHCA *actual coverage*. That is, even if all candidate locations selected by the spatial model are equipped with an AED, *actual coverage* does not exceed 300 OHCAs. The overall efficiency gain was then calculated as the decrease in the total number of AED locations required by the spatiotemporal model relative to the total number of AED locations required by the spatial-only model over all five coverage levels (32.3% = (691-468)/691). The calculation of efficiency gain is summarized in Table A1.

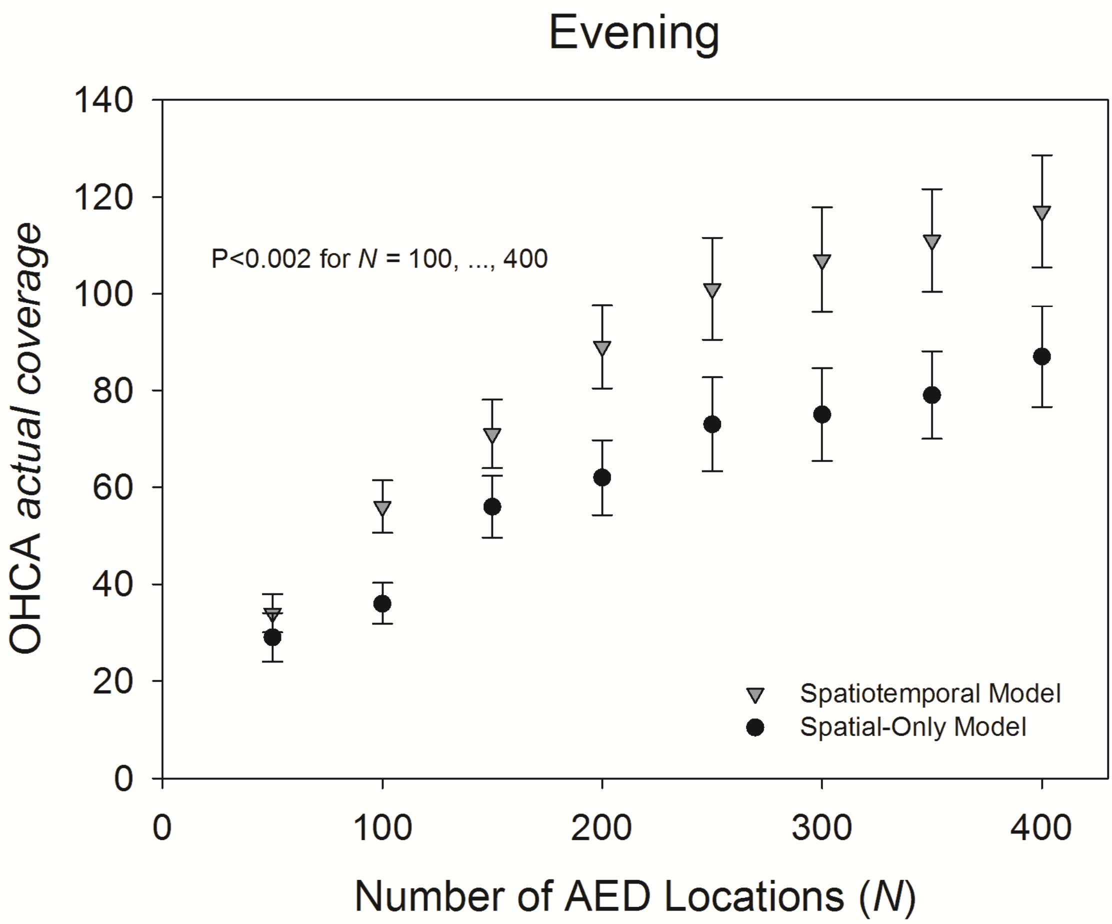
OHCA *actual coverage*	**AED locations from Spatiotemporal model (*N*)**	**AEDs locations from Spatial-only model (*N*)**	**Efficiency gain (%)**
50	14	23	39.1
100	38	60	36.7
150	85	117	27.4
200	134	188	28.7
250	197	303	35.0
Total	468	691	
Overall			32.3

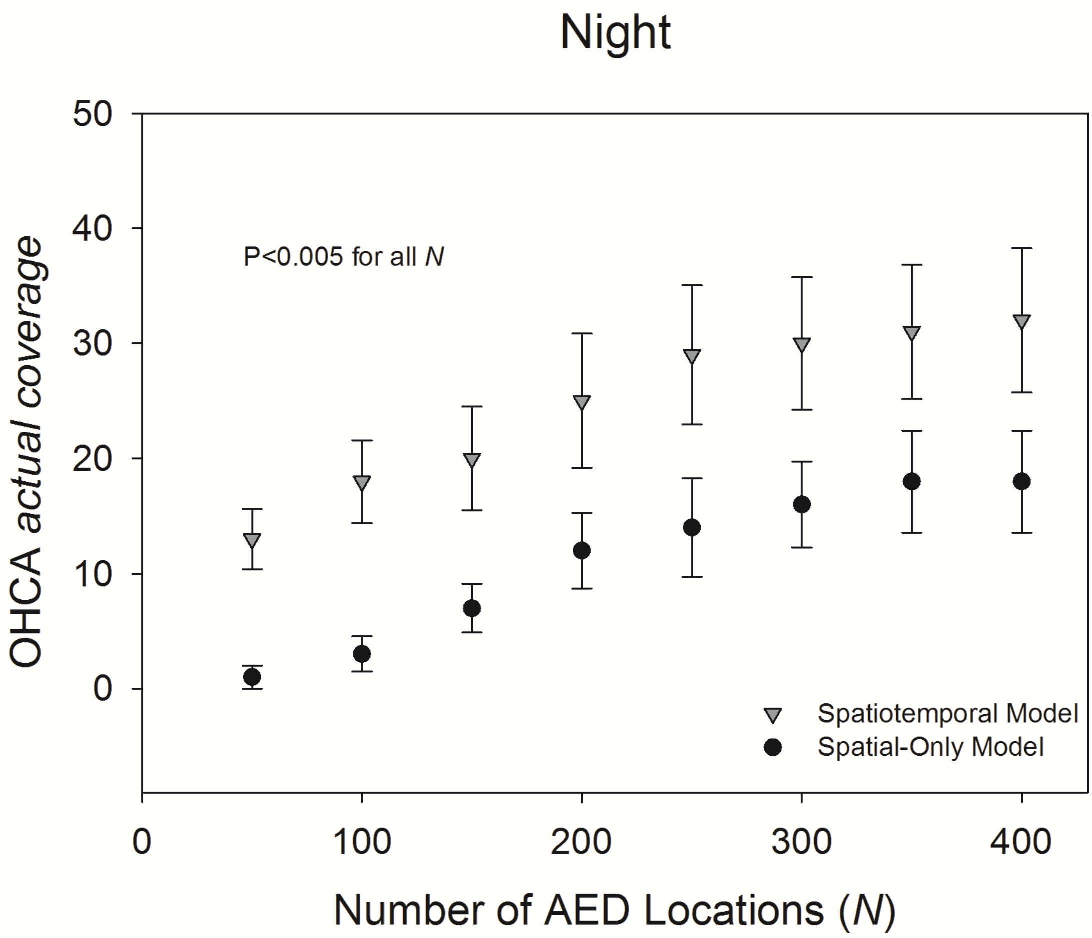
Online Table 1. Efficiency gain in *actual coverage* of testing set OHCAs from AED locations determined by the spatiotemporal and spatial-only models.

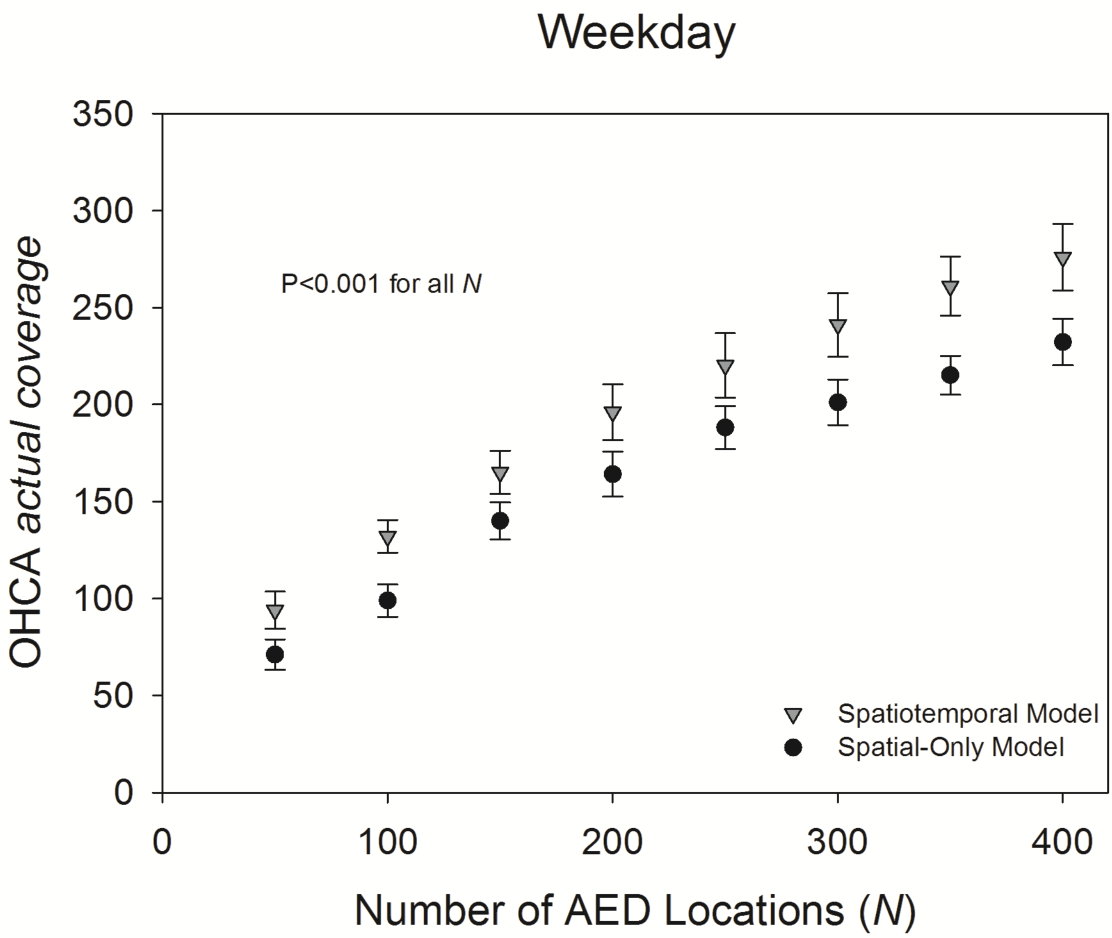
References

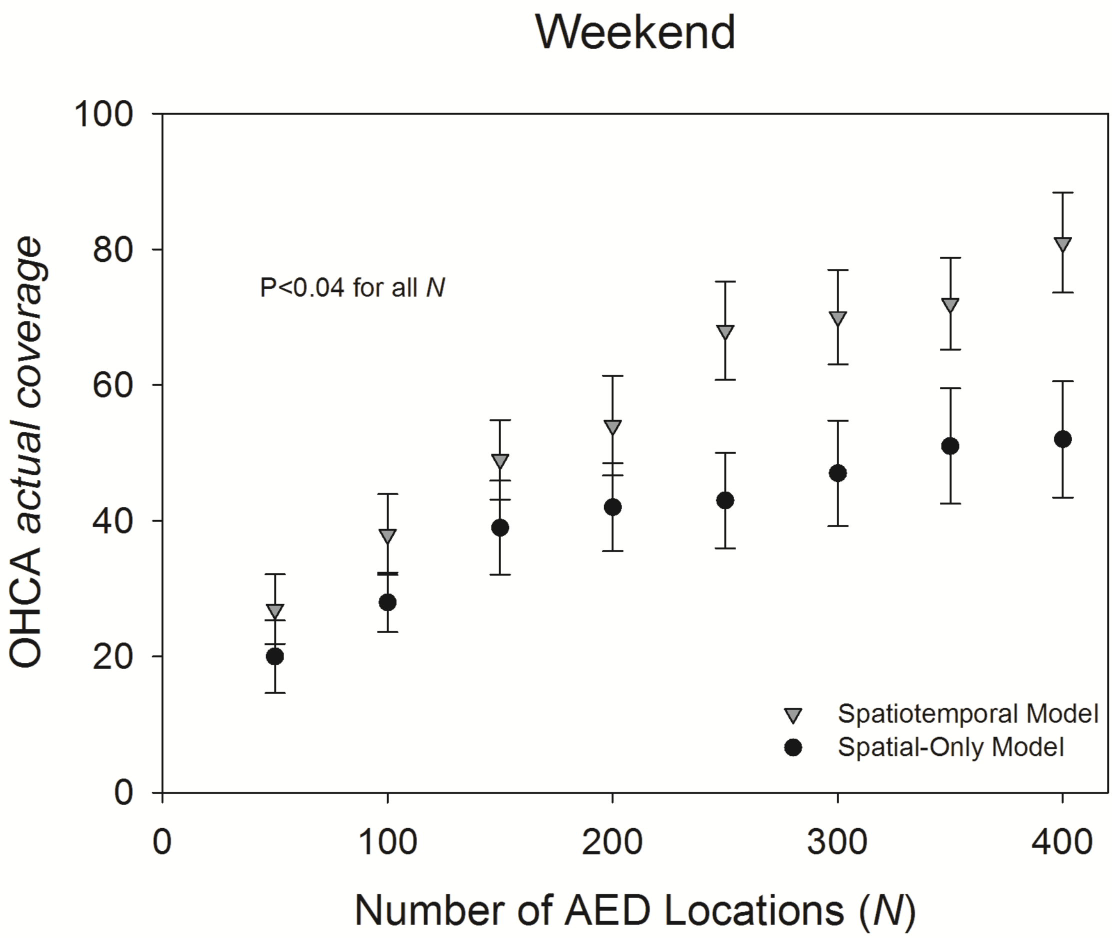
1. Chan TC, Li H, Lebovic G, et al. Identifying locations for public access defibrillators using mathematical optimization. Circulation 2013;127:1801-9.

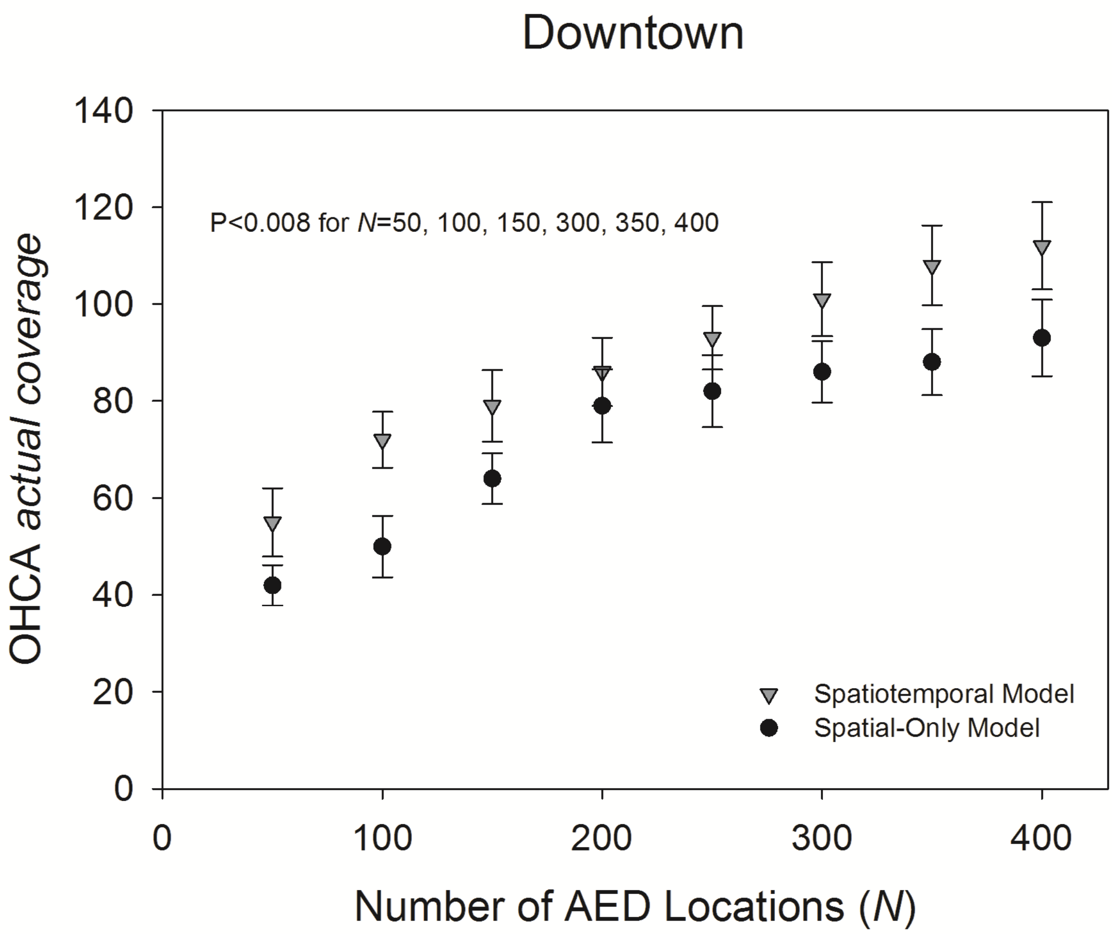

Daytime
OHCA *actual coverage*
Number of AED Locations (*N*)
P<0.02 for N=50, 350, 400
Spatiotemporal Model
Spatial-Only Model
250
200
150
100
50
0
0
100
200
300
400


Evening
OHCA actual coverage
P<0.002 for N = 100, ..., 400
Spatiotemporal Model
Spatial-Only Model
Number of AED Locations (N)
140
120
100
80
60
40
20
0
0
100
200
300
400

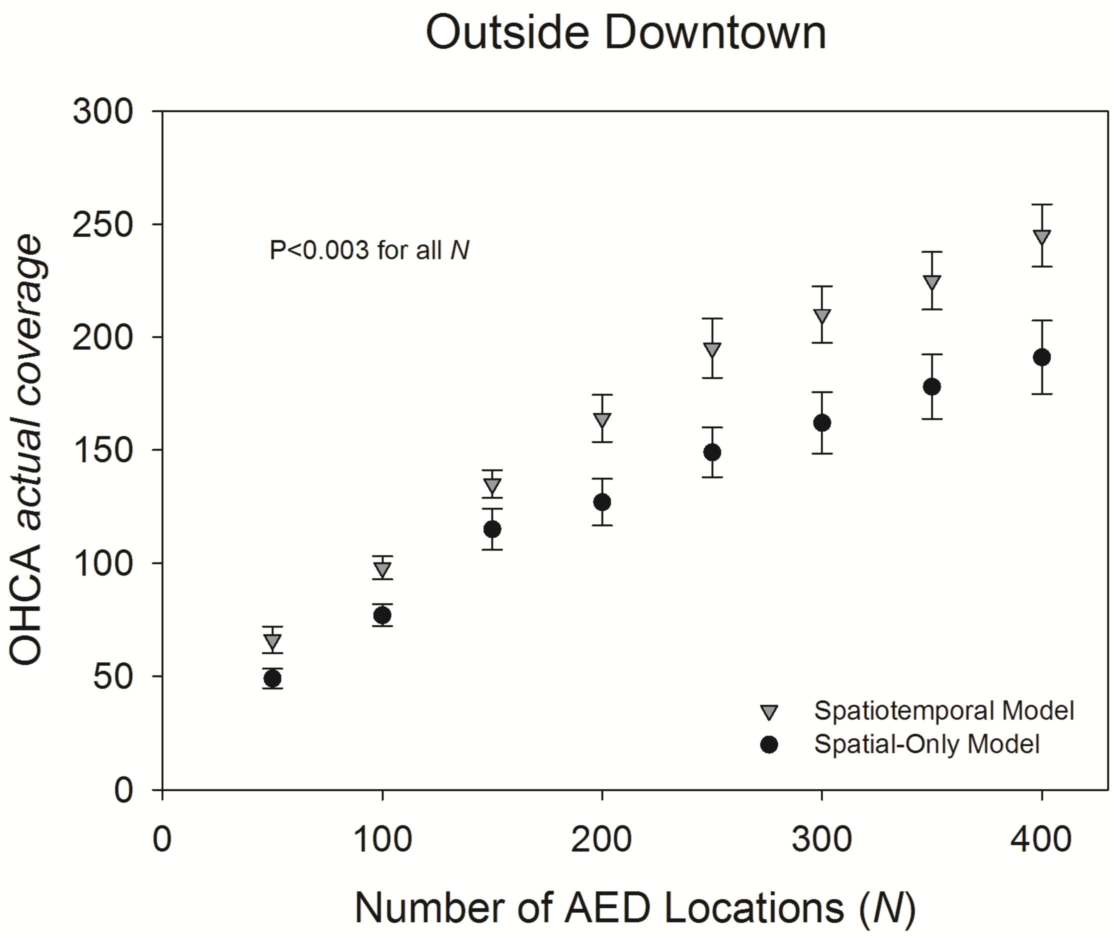

Night
50
40
30
20
10
0
OHCA actual coverage
P<0.005 for all N
Spatiotemporal Model
Spatial-Only Model
0
100
200
300
400
Number of AED Locations (N)


Weekday
OHCA actual coverage
Number of AED Locations (N)
P<0.001 for all N
Spatiotemporal Model
Spatial-Only Model
0
50
100
150
200
250
300
350
0
100
200
300
400


Weekend
100
80
60
40
20
0
OHCA actual coverage
P<0.04 for all N
Spatiotemporal Model
Spatial-Only Model
0
100
200
300
400
Number of AED Locations (N)



Downtown
P<0.008 for N=50, 100, 150, 300, 350, 400
OHCA actual coverage
Number of AED Locations (N)
Spatiotemporal Model
Spatial-Only Model
0
20
40
60
80
100
120
140
0
100
200
300
400


Outside Downtown
OHCA actual coverage
Number of AED Locations (N)
P<0.003 for all N
Spatiotemporal Model
Spatial-Only Model
0
50
100
150
200
250
300
0
100
200
300
400