**EMS Stroke Triage and Transport Model (ESTTM) Documentation**

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# Model Objectives

1. Estimate the impact of EMS stroke triage and transport plans on triage outcomes (i.e., correct, over, and under) across varying region sizes.
2. Estimate total prehospital times and EMS transport times for stroke diagnoses by algorithm specifications and region sizes.

# Model Structure and Design

**Discrete Event Simulation** (assuming non-constrained resources so no queuing)

* Base case: EMS transports all suspected stroke patients to nearest PSC or CSC
* Interventions: EMS LVO triage and transport algorithm specifications (Appendix 2)
  + LVO screen: (1) sensitivity and (2) specificity
  + (3) Additional transport time threshold (reroute to CSC if additional transport time no more than X)
* Conditions:
  + Region size (square miles)
  + EMS transport speed (mph) ∝ region size + traffic factor
  + Transport distances between patient and nearest PSC and CSC

**Entities and Attributes**

* Patients (“suspected stroke”)
  + Stroke diagnosis (AIS-LVO, AIS-non LVO, hemorrhagic, mimic)
  + Time since last known well (LKW) to 911 call
  + Location (or distances from nearest PSC and CSC)

**Events**

* Base case: EMS transports to nearest hospital
* Intervention: EMS transports per algorithm
  + EMS LVO screen (positive or negative) ∝ patient stroke type + LVO screen sensitivity + LVO screen specificity
  + EMS transport decision ∝ EMS LVO screen result + additional transport time

**Outputs/Times**

1. Nearest hospital type (PSC or CSC)
2. Destination hospital type (PSC or CSC)
3. EMS transport time to nearest hospital
4. EMS transport time to destination hospital
5. Total prehospital time (LKW to destination hospital)

# Model Parameters

**Table 1. Model Input Parameters**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Input no.** | **Input** | **Distribution** | **Parameterization** | **Source/Notes** |
| P1 | Diagnosis | Bernoulli | Not true stroke 60%  True stroke  Hemorrhagic 5.2%  Ischemic  LVO 13.5%  Non-LVO 21.3% | Lit |
| P2 | Time Since Last Known Well (LKW) to 911 call (hours) | User defined | [0,3] w.p. 0.704  [3,6] w.p. 0.075  [6,24] w.p. 0.149  [24,48] w.p. 0.072 | from NC EMS stroke 2019 data |
| P3 | Time from 911 call to EMS dispatch (min) | Constant | 1.62 | Lit |
| P4 | Time from EMS dispatch to arrival on scene (min) | Normal | Mean 15.1, SD 7 | Lit |
| P5 | Time EMS spent on scene (min) | Beta | a=2.91, b=6.056, scale=40 | Lit |
| P6 | EMS transport speed (mph) | Constant (function of region size) | 35 + (region size – 10)/2 | Ranges from 35-55 mph, e.g.,  if region is 10x10 mi2, the speed is 35 mph  if region is 50x50 mi2, then speed is 55 mph |

# Simulation Experiments

* We want to evaluate 20 different intervention scenarios (Table 2) in this analysis
* We will run 1,000 iterations for each intervention scenario, where iterations vary the uncertain parameters (in Table 1)
* We will run 500 replications for each iteration, with region size and placement of PSCs randomly varied across replications.
* Each replication includes 2,500 randomly generated patients for a randomly generated region size and placement of PSCs (Table 3).
* Each patient experiences the simulation replication in a sequence of events (Table 4).

*Each simulation will set the following:*

**Table 2. Intervention Scenarios** – EMS LVO triage and transport algorithm specification (see Table 5)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Decision** | **Description** | **Distribution** | **Parameterization** | **Source/Notes** |
| D1a | EMS LVO screen sensitivity | Constant | e.g., 70%, 80%, 90% | 5 combinations (see Table 5) |
| D1b | EMS LVO screen specificity | Constant | e.g., 70%, 80%, 90% |
| D2 | Additional transport time threshold | Constant | e.g., 15, 30, 45, 60 minutes | Jauch, et al. |

*For each simulation replication:*

**Table 3. Simulation Replication**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Step** | **Description** | **Distribution** | **Parameterization** | **Example/Notes** |
| R1 | Randomly assign region size (X by X miles) | Uniform | [20, 100] | 47 miles x 47 miles |
| R2 | Location of CSC | Constant | XY coordinates [0.5, 0.5] | Placed in the center of the region |
| R3a | Randomly assign location of PSC1 |  |  | Randomly placed at least 1 mile from CSC |
| R3b | Randomly assign location of PSC2 |  |  | Randomly placed at least 1 mile from CSC and PSC1 |
| R4 | Number of EMS-suspected stroke patients per year | Constant | 2,500 | Assuming 1,000 true stroke patients transported by EMS each year and 40% (see P1) of all EMS-suspected stroke patients are true strokes |
| R5 | Assign attributes for each patient  a. diagnosis  b. time LKW to 911 call  c. location | a. P1  b. P2  c. randomly generate XY coordinates |  | e.g., Patient #743  a. AIS-non LVO  b. 47 minutes  c. [0.56, -0.82] |

**Table 4. Patient events within a simulation replication**

|  |  |  |
| --- | --- | --- |
| **Steps** | **Description** | **Example** |
| E0a | Patient location | Square grid coordinates: 0.56, -0.82 |
| E0b | Stroke diagnosis | Patient is having an AIS-non LVO |
| E1 | Symptom onset/LKW to 911 call | 911 called after patient experienced symptoms for 47 min (LKW<4.5 hrs) |
| E2 | 911 call to EMS arrival on scene |  |
| E3 | EMS time spent on scene |  |
| E4 | EMS LVO screen | Patient screened as LVO (false positive) |
| E5a | EMS transport time to nearest PSC | Time to nearest PSC is 10 min |
| E5b | EMS transport time to CSC | Time to CSC is 42 min |
| E6 | EMS transport decision made | LKW<4.5 hrs and add’l transport time >30 min threshold so transport to nearest PSC |
| E7 | EMS departs scene for destination hospital |  |
| E8 | EMS transport time to destination hospital |  |
| E9 | Triage outcome (see “Outcomes” section below) | Although screened false positive, AIS-non LVO was correctly triaged to nearest PSC |

*Simulations (1,000 replications each) will compare the following 21 algorithm specifications:*

**Table 5. Algorithm Specifications for Each Simulation**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Simulation #** | **Description** | **Algorithm Specifications** | | |
| **EMS LVO Screen** | | **Additional transport time threshold** |
| **Sensitivity** | **Specificity** |
| 0 | Base Case | n/a | n/a | n/a |
| 1 | Moderate Se and Sp | 80 | 80 | 15 |
| 2 | “ | 80 | 80 | 30 |
| 3 | “ | 80 | 80 | 45 |
| 4 | “ | 80 | 80 | 60 |
| 5 | High Se and Low Sp | 90 | 70 | 15 |
| 6 | “ | 90 | 70 | 30 |
| 7 | “ | 90 | 70 | 45 |
| 8 | “ | 90 | 70 | 60 |
| 9 | Low Se and High Sp | 70 | 90 | 15 |
| 10 | “ | 70 | 90 | 30 |
| 11 | “ | 70 | 90 | 45 |
| 12 | “ | 70 | 90 | 60 |
| 13 | Low Se and Sp (worst case) | 70 | 70 | 15 |
| 14 | “ | 70 | 70 | 30 |
| 15 | “ | 70 | 70 | 45 |
| 16 | “ | 70 | 70 | 60 |
| 17 | High Se and Sp (best case) | 90 | 90 | 15 |
| 18 | “ | 90 | 90 | 30 |
| 19 | “ | 90 | 90 | 45 |
| 20 | “ | 90 | 90 | 60 |

# Study Outcomes

1. Triage outcomes
   1. Correct triage
      1. If any stroke type other than LVO, then transport to nearest
      2. If LVO, then transport to CSC
   2. Under triage
      1. If LVO, then transport to PSC
   3. Over triage
      1. If any stroke type other than LVO, then transported to CSC when PSC was nearest
2. Times (overall and by patient diagnoses and triage outcomes)
   1. Prehospital time (mean, SD, median, IQR, min, max)
   2. EMS transport time (mean, SD, median, IQR, min, max)

# Analyses

1. One seed and one map (w/ 2,500 patients)
   1. Compare each scenario to base case (different, how much, rank order by correct triage (only scenarios 1-12))
   2. Just numbers
2. Change seed (higher the number the better 1,000) for the one map (“replications”)
   1. Percentiles 5th, 25th, 75th, 95th
3. Across maps (region size and PSC placements\*)
   1. How do rank orders change by map characteristics?

\*mean additional travel distance/time to CSC?