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

\*\*\*EXTENDED (includes treatment times, transfers, and patient outcomes)\*\*\*

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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) and patient outcome (i.e., 90-day modified Rankin Score (mRS)) across varying regions.
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
  + 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
  + 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)
6. IVT/EVT treatment times
7. Probability of mRS 0-1 at 90 days

# 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%  Acute Ischemic  LVO 13.5%  Non-LVO 21.3% | Lit |
| P2 | Time Since Last Known Well (LKW) to 911 call (hours) | User defined | [0.1,3] w.p. 0.44  [3,6] w.p. 0.22  [6,24] w.p. 0.29  [24,48] w.p. 0.05 | ~~Lit~~ |
| 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) | If region size <= 70:  = 25 + (region size – 30)/2  If region size >70:  = 45 | Ranges from 25-45 mph |
| P7 | Door to IVT (min) | Constant | 45 |  |
| P8 | Door to EVT (min) | Constant | 90 |  |
| P9 | IVT to door out (min) | Constant | 45 | For LVO transferred to CSC |
| P10 | Door to EVT(2) (min) | Constant | 45 | Door to EVT time at destination CSC |

**Time to IVT/EVT calculation:**

1. tonset to IVT= (LKW to door) + (Door to IVT)
2. tonset to EVT
   1. If 1st hospital = CSC
      1. = (LKW to door) + (Door to EVT)
   2. If 1st hospital = PSC
      1. = (LKW to door) + (Door to IVT) + (IVT to door out) + (Transfer time) + (Door to EVT(2))

**Patient outcome calculation:**

Prob(mRS 0-1) | stroke diagnosis & time to IVT/EVT**[[1]](#footnote-1)** =

1. Not stroke 0.90
2. Hemorrhagic 0.24
3. Non-LVO Acute Ischemic
   1. No IVT: 0.4622
   2. IVT: 0.6343−0.00000005(tonset to IVT)2−0.0005(tonset to IVT)
      1. Min = 0.4962 (269 min); Max = 0.6338 (1 min)
4. LVO Acute Ischemic
   1. No IVT/EVT: 0.129
   2. IVT only: 0.2359+0.0000002(tonset to IVT)2-0.0004(tonset to IVT)
      1. Min = 0.1428 (269 min); Max = 0.2355 (1 min)
   3. EVT only: 0.3394+0.00000004(tonset to EVT)2−0.0002(tonset to EVT)
      1. Min = 0.1343 (1,440 min); Max = 0.3392 (1 min)
   4. IVT+EVT: IVT+((1-IVT)\*EVT)
      1. Min = 0.2579 (1,440 min); Max = 0.4947 (2 min)

# Simulation Experiments

* Evaluate 19 different scenarios (Table 2 – 1 base case and 18 interventions)
* Generate 100 random maps (Table 3)
* Generate 2,500 random patients and sequences of events with 40 seeds (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., 60%, 75%, 90% | 5 combinations (see Table 5) |
| D1b | EMS LVO screen specificity | Constant | e.g., 60%, 75%, 90% |
| D2 | Additional transport time threshold | Constant | e.g., 10-60 minutes by 10 minutes | Jauch, et al.[[2]](#footnote-2) |

*For each simulation replication:*

**Table 3. Simulation Replication**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Step** | **Description** | **Distribution** | **Parameterization** | **Example/Notes** |
| R1 | Randomly assign region size (X by X miles) | Uniform | [30, 130] | 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 |

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

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Scenario #** | **Description** | **Algorithm Specifications** | | |
| **EMS LVO Screen** | | **Additional transport time threshold** |
| **Sensitivity** | **Specificity** |
| 0 | Base Case | n/a | n/a | n/a |
| 1 | High Se and Low Sp | 90 | 60 | 10 |
| 2 | 90 | 60 | 20 |
| 3 | 90 | 60 | 30 |
| 4 | 90 | 60 | 40 |
| 5 | 90 | 60 | 50 |
| 6 | 90 | 60 | 60 |
| 7 | Moderate Se and Moderate Sp | 75 | 75 | 10 |
| 8 | 75 | 75 | 20 |
| 9 | 75 | 75 | 30 |
| 10 | 75 | 75 | 40 |
| 11 | 75 | 75 | 50 |
| 12 | 75 | 75 | 60 |
| 13 | Low Se and High Sp | 60 | 90 | 10 |
| 14 | 60 | 90 | 20 |
| 15 | 60 | 90 | 30 |
| 16 | 60 | 90 | 40 |
| 17 | 60 | 90 | 50 |
| 18 | 60 | 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)
3. Probability of mRS 0-1

# Analyses

1. For each patient, compare outcomes for each scenario to the base case (compute differences)
2. For each cohort of patients, compute mean differences
3. For each map, compute mean and 90% uncertainty interval (5th to 95th percentiles across random number seeds

1. Reference: Holodinsky JK, Williamson TS, Demchuk AM, Zhao H, Zhu L, Francis MJ, Goyal M, Hill MD, Kamal N. Modeling stroke patient transport for all patients with suspected large-vessel occlusion. JAMA neurology. 2018 Dec 1;75(12):1477-86. [↑](#footnote-ref-1)
2. Jauch EC, Schwamm LH, Panagos PD, Barbazzeni J, Dickson R, Dunne R, Foley J, Fraser JF, Lassers G, Martin-Gill C, O’Brien S. Recommendations for regional stroke destination plans in rural, suburban, and urban communities from the prehospital stroke system of care consensus conference. Stroke. 2021 May;52(5):e133-52. [↑](#footnote-ref-2)