A Statistical Model for Emergency Medical Services Response to Motor Vehicle Crashes in Michigan

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Introduction

The response time is a crucial element of Emergency Medical Services (EMS). However, there are neither federal nor state (specifically Michigan) laws in place to regulate EMS response times, and standards are being set by individual vendors or local organizations. Investigation into response time performance measures may lead to further discoveries, innovations, and potentially identify best practices to improve existing systems used by EMS. Leading to quicker access to care for the end users (crash victims) and potentially saving numerous human lives.

Parameters Effecting Response

- Emergency Response System Used
- EMS availability in crash area
- Driving distance
- Geographic classification (rural or urban)
- Traffic conditions of the route
- EMS vehicle condition

Sprawling of Cities

- No. of sever crashes & EMS response varies by location (urban and rural) (1, 2, 3).
- Movement to the suburbs: low cost of goods/services, affordable homes, lower taxes, and more privacy (4).
- Longer and further commute for work and to some services (4).

American Heart Association: Timely Response to Cardiac Arrest (5)

- Optimal service of necessary defibrillation must be preformed within 8 minutes of the episode.
- Brain death and permanent death begin to occur 4-6 minutes after patient experiences cardiac arrest.
- Victim's chance of survival are reduced by 7% - 10% with every minute that passes without defibrillation and advanced life support intervention.
- Cardiopulmonary Resuscitation (CPR) should be initiated within 4 minutes and defibrillation within 8 minutes of initial arrest

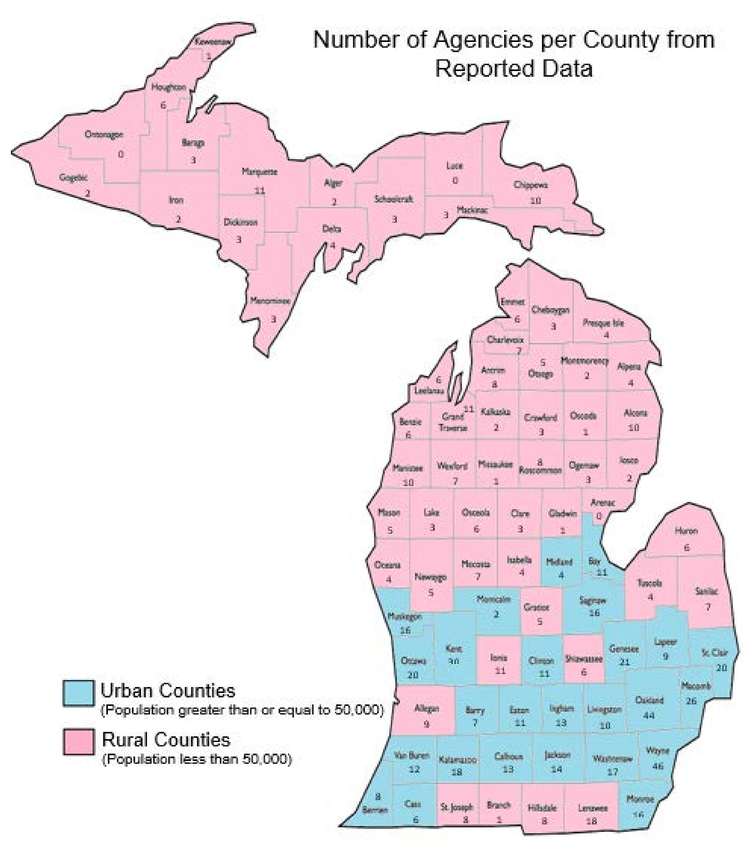
Modeling Response Time as an Outcome Measure

Response time, as an outcome measure, has been evaluated by researchers to identify the potential effect on patient care and outcome in conjunction with different strategies such as vehicle location, urban vs rural, transport location, etc. Various modeling methods have been used to conduct such evaluations.

Pons & Markovichic (6)	Evaluated the effect of exceeding the 8 minute response guideline on patient survival for victims of traumatic injury.
Ong et al. (7)	Researched the implementation of the geospatial-time analysis to reduce ambulance response times for out-of-hospital cardiac arrests in urban EMS systems.
Repede & Bernardo (8)	Used a maximal expected coverage location model with time variation (TIMEXCLP), integrating the results into a decision support system to allocate vehicle location within service area.

Although the models and approaches cited above are available in various journals, it is to be noted that each study was conducted with a specific objective and utilized either nationally available data or a subset of specific data collected for the purpose.

Rural & Urban Classification



- Geographic classification was determined by population density
- Urban: populations greater than or equal to 50,000 residents (9).
- Rural: populations less than 50,000 (9).

83 Counties
57 Rural
26 Urban

State of Michigan EMS Response Time Data

Response Time Data Treatment (No. Removed)
Missing Unit Notified Time (123)
Missing Unit Arrived Time (2,315)
Missing both Unit Notified and Unit Arrived Time (432)
Negative Response Time Calculation (767)
Outside Lower Threshold: 2 minutes (38,962)
Outside Upper Threshold: 120 minutes (226)
Misclassified Data (61,854)
Remaining Values: 240,473

The data utilized within this study was motor vehicle crash (MVC) data collected in the state of Michigan from January 2010 through March 2015. The data did not contain any identifiers of the accident victims or the EMS personnel involved at the crash sites. Custom codes were written to extract and organize the 409,973 records (rows of data) from the provided database. This does not imply that each row of data had all fields completed. Rather, it simply implies the presence of 409,973 unique incident numbers.

Data Treatment

When compiling the master data it was assumed that all incidents took place within the borders of Michigan, and occurred between January 2010 and February 2015. Test and training data were not considered for testing and any non-motor vehicle related crash data were disregarded as well. This resulted in a master dataset of 283,298 unique incidents, or 69% of the raw data. Additional removal of incidents from the master dataset was conducted based on specified response time criteria, resulting in 240,473 unique incidents or 59% or the raw data.

$$\textit{Response Time} = \textit{Time of Unit Arrival on Scene} - \textit{Time of Unit Notification}$$

Preliminary Linear Modeling

- Dependent Variable: Response Time (including arithmetic transformations)
- Independent Variables (single and/or combination):
  - No. of Response Vehicles by County
  - Time of Day
  - Population by County
  - Rural or Urban Classification
  - Ratio: Population to No. of Response Vehicles by County
- R-squared values less than 15%, suggesting weak relationships between response time and corresponding independent variable(s).

Linear Regression Variables	R-Squared Value	R-Squared Predicted
Logarithm of Response Time vs No. of Response Vehicles by County and Rural or Urban Classification	14.88%	14.88%
Logarithm of Response Time vs No. of Vehicles by County	9.58%	9.58%
Logarithm of Response Time vs No. of Response Vehicles by County	12.90%	12.90%
Logarithm of Response Time vs No. of Response Vehicles by County and Time of Day	10.06%	10.06%
Logarithm of Response Time vs Population by County, No. of Response Vehicles by County, and Rural or Urban Classification	14.90%	14.89%
Logarithm of Response Time vs Logarithm of Population and Rural or Urban Classification	13.68%	13.68%
Logarithm of Response Time vs Ratio of Population to No. of Response Vehicles and Rural or Urban Classification	12.15%	11.94%

65 Distributions: Goodness-of-Fit Tests

Chi-Squared Test

The goodness of fit between the experimental data and the theoretical distribution is centered on the ability of Equation 1 to approach a Chi-Squared distribution as n approaches infinity (10).

$$\sum_{i=1}^{k} \frac{(n_i - e_i)^2}{e_i} \qquad (1)$$

Kolmogorov Smirnov Test

Compares cumulative frequency of observed data with the cumulative density function (CDF) of the known theoretical distribution. The common issue of only having a small number of intervals available for Chi-Squared testing can be avoided (10).

Anderson Darling Test

Evaluates the logarithms of the experimental and theoretical probabilities. More emphasis is placed on the analysis of extreme points or tails of the distributions (10).

3-Parameter Lognormal Model

The goodness-of-fit results suggest that the 3-Parameter Lognormal Distribution is one of the most suitable distributions for future predictive modeling. The 3-Parameter Lognormal Distribution was identified as the highest ranking distribution based on the Anderson Darling test, however, distributions such as Pearson 6 (4P), Inverse Gaussian, and others also presented plausible fits and may be considered in future modeling studies.

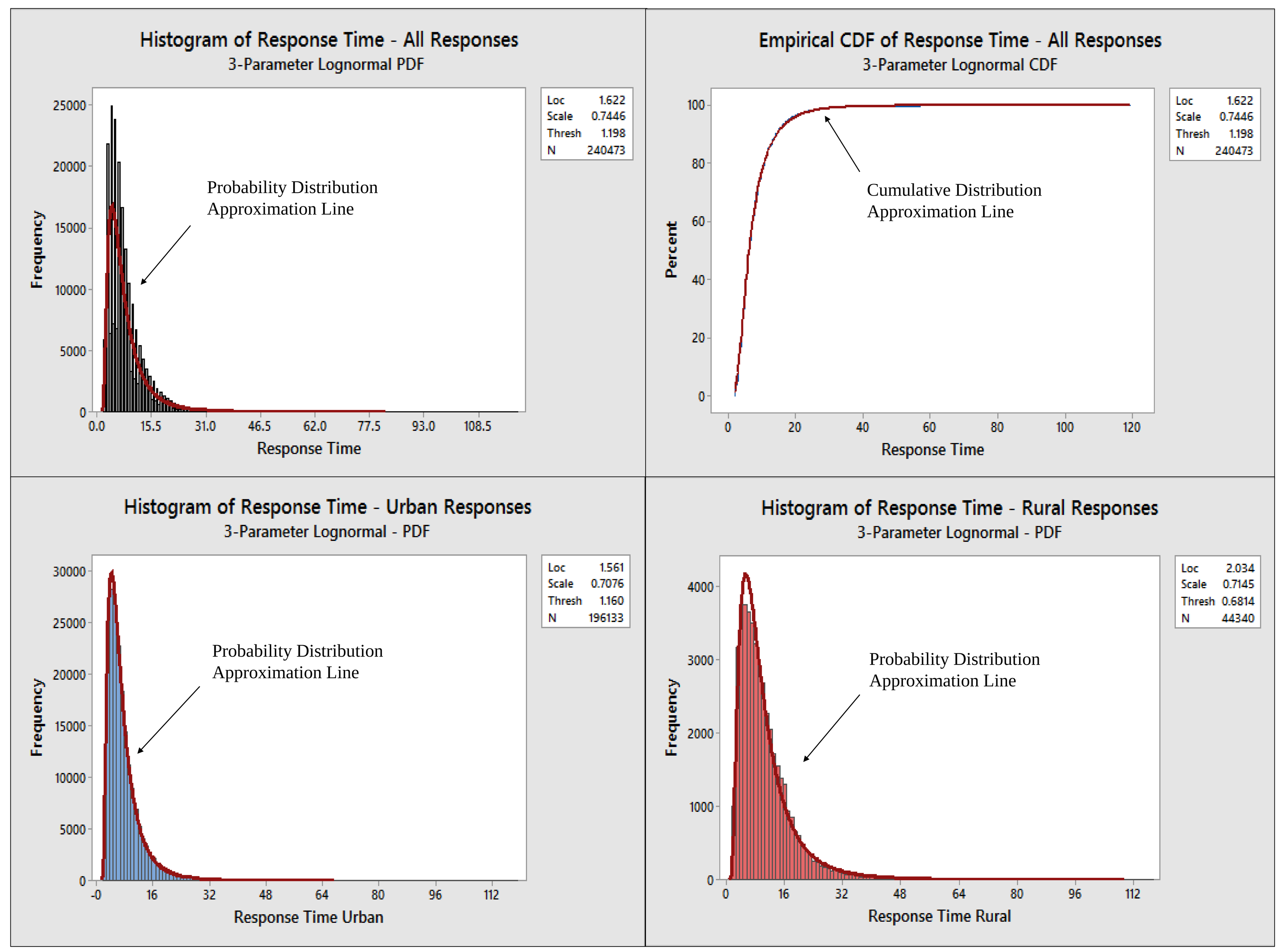
Probability Distribution Function (PDF)

$$f(x) = \frac{exp\left(-\frac{1}{2}\left(\frac{\ln(x-\gamma)-\mu}{\sigma}\right)^2\right)}{(x-\gamma)\sigma\sqrt{2\pi}}$$

Cumulative Distribution Function (CDF)

$$F(x) = \phi\left(\frac{\ln(x-\gamma)-\mu}{\sigma}\right)$$

Where the three parameters $\mu, \sigma,$ and γ contribute to the location, scale, and threshold properties of the distribution, respectively. Additionally, ϕ is understood to be the Laplace Integral and π the mathematical constant for computational purposes.



Fitted Data: 3-Parameter Lognormal Model (minutes)

Response Times	Fitted Mean (μ_F)	Fitted Standard Deviation (σ_F)	Time Interval $\mu_F \pm \sigma_F$ (68% of data)	Time Interval $\mu_F \pm 2\sigma_F$ (95% of data)	Time Interval $\mu_F \pm 3\sigma_F$ (99.7% of data)
All	6.26	3.30	(3.60, 11.86)	(2.34, 23.65)	(1.74, 48.46)
Urban	5.96	3.23	(3.55, 10.86)	(2.35, 20.81)	(1.77, 40.99)
Rural	8.84	3.24	(4.94, 16.82)	(3.03, 33.11)	(2.09, 66.40)

Note: μ_F and σ_F are the mean and standard deviation for the fitted 3-parameter lognormal model.

Collected EMS Data Descriptive Statistics (minutes)

Response Times	EMS Mean (μ)	EMS Standard Deviation (σ)
All	7.87	5.82
Urban	7.28	5.04
Rural	10.51	7.94

Application of Fitted Response Time Distribution

- Evaluate and compare EMS agency performances: response times to fall within the 68%, 95%, or 99.7% time intervals.
- 3-Parameter Lognormal Distribution classifications can be evaluated and adjusted as more data is collected.
- The PDF and CDF can be used to predict and summarize response times.
- Use the distributions in queuing or simulation models to test changes in protocols or the routing and location of agency vehicles.
  - Without additional information, models for prediction will be extremely rudimentary and have very low power for prediction.
- Combine current data fields with additional data from other sources, higher powered prediction models could be developed to provide means for EMS performance evaluation and for response time improvements.
  - agency characteristics
  - population information and demographics specific to counties or regions
  - GPS data and/or vehicle routes taken to and from a scene.
- A complementary approach to future modeling of this data is big data analytics.

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