Identification and Analysis of Key Dynamics Required for Sustainable Planning of the Texas Trauma System

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TEXAS Health and Human Services

Texas Department of State Health Services

AGENDA

MOTIVATION

BACKGROUND

RESEARCH OBJECTIVES

PROPOSED METHODOLOGY

CONCLUSIONS

MOTIVATION

Trauma injuries can lead to the death if proper care is not administered to the patient on a timely fashion.

Easy access to trauma care centers (TCC) is even more important when considering unexpected events such as the COVID-19 pandemic.

TCCs are uniquely impacted by COVID-19 given the need for rapid invasive interventions in severely injured and the growing incidence of community infection.

Trauma incidents are one of the leading causes for disability, mortality, and morbidity for patients under the age of 44 in the U.S. and has an economic burden of $671 billion annually.

Multiple studies have concluded that access to trauma care centers (TCC) is not even for all populations, especially rural and urban groups.

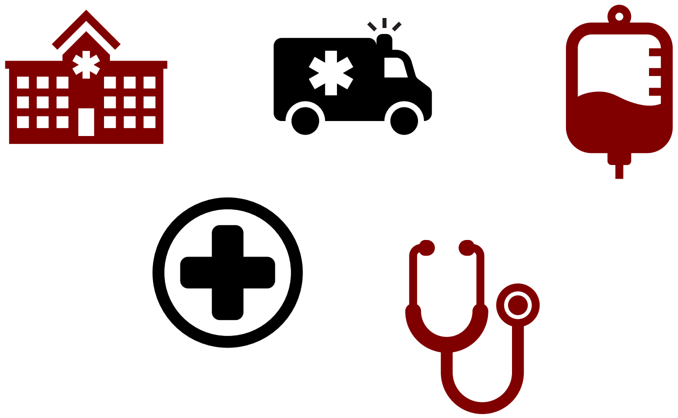
MOTIVATION

- This research studies the design and expansion of the state of Texas trauma care system
- The state of Texas plans to expand the availability of high-level trauma centers as laid out in the 2019-2020 Texas State Health Plan
- The report recommended a comprehensive study to ascertain the true extent of accessible trauma care for the state particularly for rural zones that have limited road networks to provide access and services.
- 32.4% of Texans live further than 20 miles from a Level-I TCC and 12.1% live a distance of more than 50 miles.
- Poor access to trauma care services result in higher mortality rates among citizens before hospital admissions (**Hashmi et al. 2019**)

BACKGROUND

A study conducted in 2018 showed 280 state designated trauma facilities in Texas.

- Level I Trauma Centers: **18**
- Level II Trauma Centers: **23**
- Level III Trauma Centers: **54**
- Level IV Trauma Centers: **185**



- TCCs are classified as Level-I to Level-IV
- Level-I and Level-II TCCs offer the highest level of services to patients with traumatic injuries.
- Level-III and Level-IV are intermediate facilities that help in stabilizing the patient.

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BACKGROUND

Current Research

- **Branas et al. (2000)** developed the TRAMAH (Trauma Resource Allocation Model for Hospitals and Ambulances) to determine travel times for patients to reach trauma centers.
- **Horst et al. (2017)** proposed to add new trauma centers to an existing framework using geospatial mapping.
- **Ahmadi- Javid et al.(2017)** reviewed papers discussing the various location-allocation models present for solving trauma center accessibility. The focus is to maximize access to patients.

Limitations of Current Research

- Deterministic population groups do not account for **uncertainty in demand**. Uncertainty into models must be incorporated.
- **Hierarchical trauma levels** not incorporated into present day models. Models assume every trauma facility treats all injuries.
- Transportation networks are and speed limits are not considered. Studies do not show varying driving times according to **changing speed limits**.

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RESEARCH OBJECTIVES

The two major objectives of this research are:

1. To collect and analyze data on trauma injuries at different population regions in Texas (i.e. cities, suburban, and rural) and to forecast service needs based on zip code locations.

2. To develop a decision-making model for the Stochastic Trauma System Configuration Problem (STSCP)

LIMITATIONS

- Data analysis performed **using Public Use Data Files (PUDF)**
  - EMS 2014 - 2016
  - Trauma 2014 - 2016
- Data limited in terms of providing a patient identifier
- Injury locations were provided with **3-digit zip codes** (each three-digit zip code includes multiple counties)

IRB

- September 16, 2019, IRB submitted
- October 14, 2019, Revisions submitted
- November 1, 2019, Revisions submitted
- December 10, 2019, Revisions submitted
- February 12, 2019, Packet forwarded to management
- April 13, 2020, Package reviewed by legal department
- May 19, 2020, Dr. Perez presented research to DSHS
- August 5, 2020, Dr. Perez asked for status
- August 12, 2020, Dr. Perez asked for status – sent to legal, review, and approval
- September 28, 2020, Dr. Perez asked for status – waiting legal, review, and approval

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Research Objective 1

METHODOLOGY

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METHODOLOGY

Research Objective 1 : To collect and analyze data on trauma injuries at different population regions in Texas (i.e. cities, suburban, and rural) and to forecast service needs based on zip code locations.

3 separate stages:

Stage 1: Generation of data sets for analysis

Stage 2: Evaluate several forecast models based on time series

Stage 3: Analyse results as a function of forecast accuracy and variability

METHODOLOGY

Texas Health and Human Services
Texas Department of State Health Services

Research Objective 1 [Stage 1]:

- Texas State Health Department provided data for a period of three years.

Table 1. Summary of key fields for trauma accidents

Field	Description	Units
Regional location	Regional location of the accident where trauma injury is reported	Location is based on zip codes
Trauma center	Level of TCC providing care to the patient	The trauma center level ranges from I to IV. Level-I provides most comprehensive care
Injury Severity Score (ISS)	Index provided by the trauma facility based on the patient health condition at the time of the arrival.	Score goes from 1 to 75 on an ascending basis
Injury environment	Environment where the injury took place (i.e. industrial complexes, streets and highways, public buildings, etc.)	Environment type designated by codes ranging from 849.0 to 849.9
Injury date	The date the injury was reported	Month, day, year
TCC service demand	The number of trauma injuries reported daily per region. This is the variable of interest which will be forecasted using the models.	Number of injuries expected per region

Table 2. Descriptive analysis class structures for trauma accidents

Class (C_i)	Description	Class members $\{ c \mid c \in C_i \}$
C_L	Regional location	(786, 780, …)
C_C	Trauma center	(Level-I, Level-II,…)
C_T	Injury severity score	(1, 2, 3, 4, 5,…, 75)
C_I	Injuries environment	(Homes, industrial, road, public building)

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METHODOLOGY

Research Objective 1 [Stage 2]:

Forecasting Models and Parameters:

- Forecast Models will use subjective or objective information for the prediction of an outcome of one or more periods in the future setting.
- Propose to employ class of models based on Exponentially Weighted Moving Average (EWMA)

Parameter	Description
$\hat{Y}_t$	denotes the supply forecast in time t
Y_t	denotes the observation of the supply in time t
$\hat{X}_t$	denotes estimates of the level or systematic component
T_t	denotes estimates of the level or systematic trend
I_t	denotes estimates of the level or systematic seasonality
m	denotes the number of periods in the seasonal cycle
τ	denotes the number of periods in the forecast lead time
b	denotes slope or rate of change of Y given X_{nt}
X_{nt}	denotes a predictor of Y

METHODOLOGY

Research Objective 1 [Stage 2]:

- The selection of the appropriate model is based on the existence of a trend and/or seasonality in the plotted time series.
- Trends to be investigated in this research are Holt's (Additive) and, if with seasonality, then Holt-Winter (Multiplicative)

Table 4. Forecast models

Model	Forecast equation	Parameters
Moving average	$\hat{X}_t = n^{-1}(\sum_{i=1}^{n} Y_{t-1})$ $\hat{Y}_t = \hat{X}_t$	n
EWMA (*simple exponential smoothing*)	$\hat{X}_t = \hat{X}_{t-1} + \alpha(Y_{t-1} - \hat{X}_{t-1})$ $\hat{Y}_t = \hat{X}_t$	α
EWMA-additive trend (*Holt's method*)	$\hat{X}_t = \alpha Y_t + (1-\alpha)(\hat{X}_{t-1} + T_{t-1})$ $T_t = \beta(\hat{X}_t - \hat{X}_{t-1}) + (1-\beta)T_{t-1}$ $\hat{Y}_t = \hat{X}_t + T_t$	α, β
EWMA-additive trend and seasonality (*Winter's method*)	$\hat{X}_t = \alpha(Y_t/I_{t-m}) + (1-\alpha)(\hat{X}_{t-1} + T_{t-1})$ $T_t = \beta(\hat{X}_t - \hat{X}_{t-1}) + (1-\beta)T_{t-1}$ $I_t = \gamma\left(\frac{Y_t}{\hat{X}_t}\right) + (1-\gamma)I_{t-m}$ $\hat{Y}_{t(\tau)} = (\hat{X}_t + \tau T_t)I_{t+\tau-m}$	α, β, γ, m
ARIMA	$\hat{Y}_t = c + \sum_{i=1}^{p} a_i Y_{t-i} - \sum_{i=1}^{q} b_i \epsilon_{t-1} + \epsilon_t$	a, b, c

METHODOLOGY

Research Objective 1 [Stage 3]:

- Analyzing the results as a function of forecast accuracy.
- Partitioning the data as in-sample(), used to estimate the forecast model parameters, and out-of-sample(), used to estimate the accuracy of the model.
- MA, EWMA, and ARIMA will be fitted to in-sample() time series.
- The appropriate EWMA model will be selected based on the existence of trend or seasonality in the series.
- MAPE will be applied to the out-of-sample data to assess model validity for future time periods.
- MAPE is calculated as shown below:

$$MAPE = T_0^{-1}\left[\sum_{t=T}^{T+T_0}\left|\frac{\hat{Y}_{t+1|t} - Y_{t+1}}{Y_{t+1}}\right|\right] * 100$$

- Also used to evaluate the improvement in the forecast across series given different information classes.

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CASE STUDY

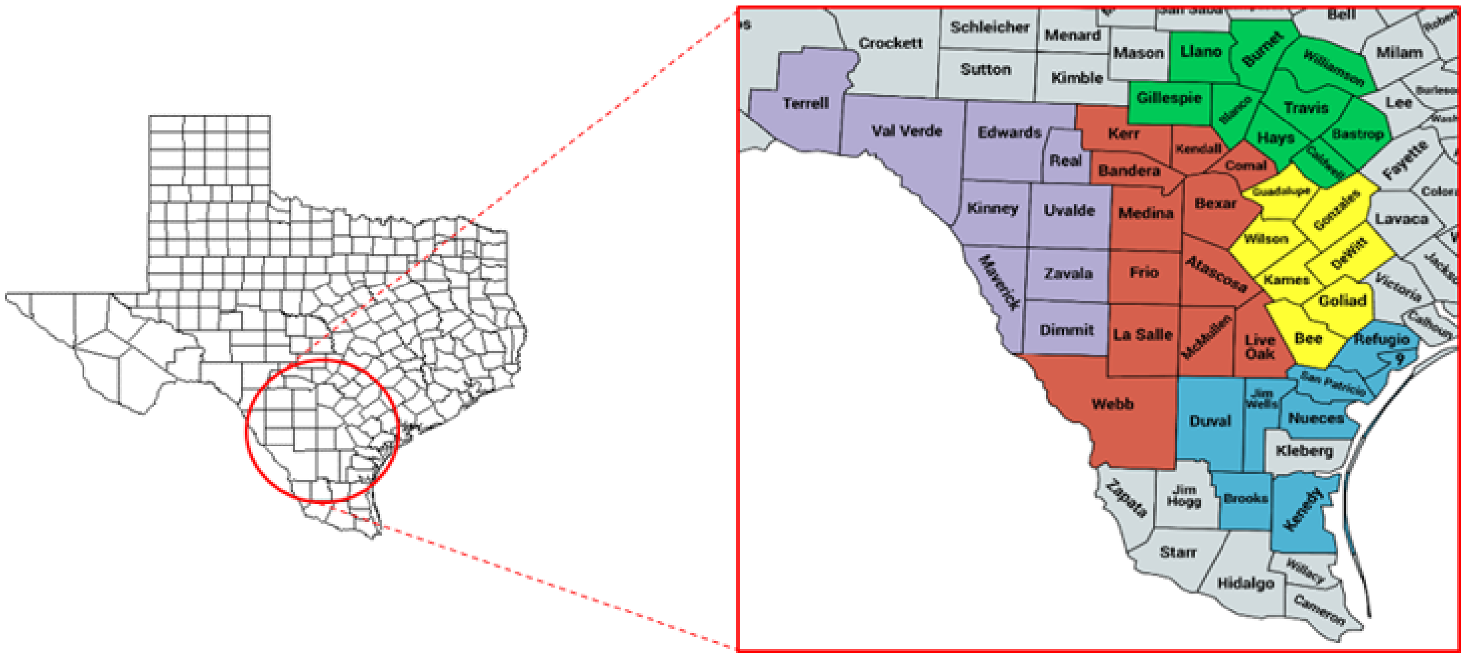

Figure 1. Texas state counties considered in this study

Table 5. Zip code associated with the counties considered in this study

Injury location (3-digit zip code)	Counties
780	Atascosa, Bandera, Bexar, Comal, Frio, Kendall, Kerr, Live Oak, Medina
781	Bee, Bexar, Comal, De Witt, Gonzales, Guadalupe, Karnes, Wilson
782	Bexar, Comal
783	Aransas, Bee, Brooks, Duval, Jim Hogg, Jim Wells, Kenedy, Kleberg, Live Oak, Nueces, Refugio, San Patricio, Webb
786	Bastrop, Blanco, Burnet, Caldwell, Comal, Gillespie, Gonzales, Guadalupe, Hays, Llano, Travis, Williamson
787	Travis, Williamson, Hays
788	Bandera, Dimmit, Edwards, Kinney, Maverick, Medina, Real, Terrell, Uvalde, Val Verde, Zavala

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DESCRIPTIVE ANALYSIS RESULTS

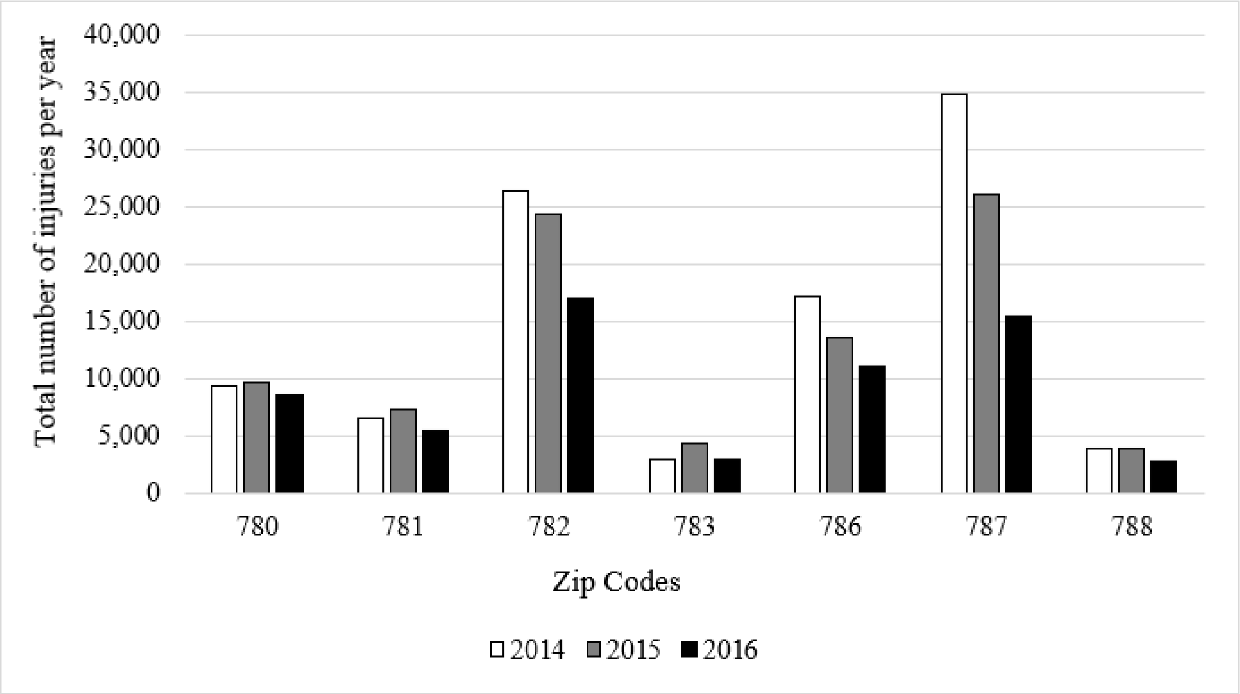

Figure 2. Number of trauma injuries reported per zip code for years 2014, 2015, and 2016

- An important insight from this graph is the declining trend for the three regions with the highest numbers.
- The rest of the regions show an increase in the number of cases from 2014 to 2015 and then a decline from year 2015 to 2016.
- It is important to consider the variable patterns for regions 780, 781, 783, and 788 since these are mostly rural regions.
- Understanding the variability in these regions is important for the future expansion of the trauma network in Texas.

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DESCRIPTIVE ANALYSIS RESULTS

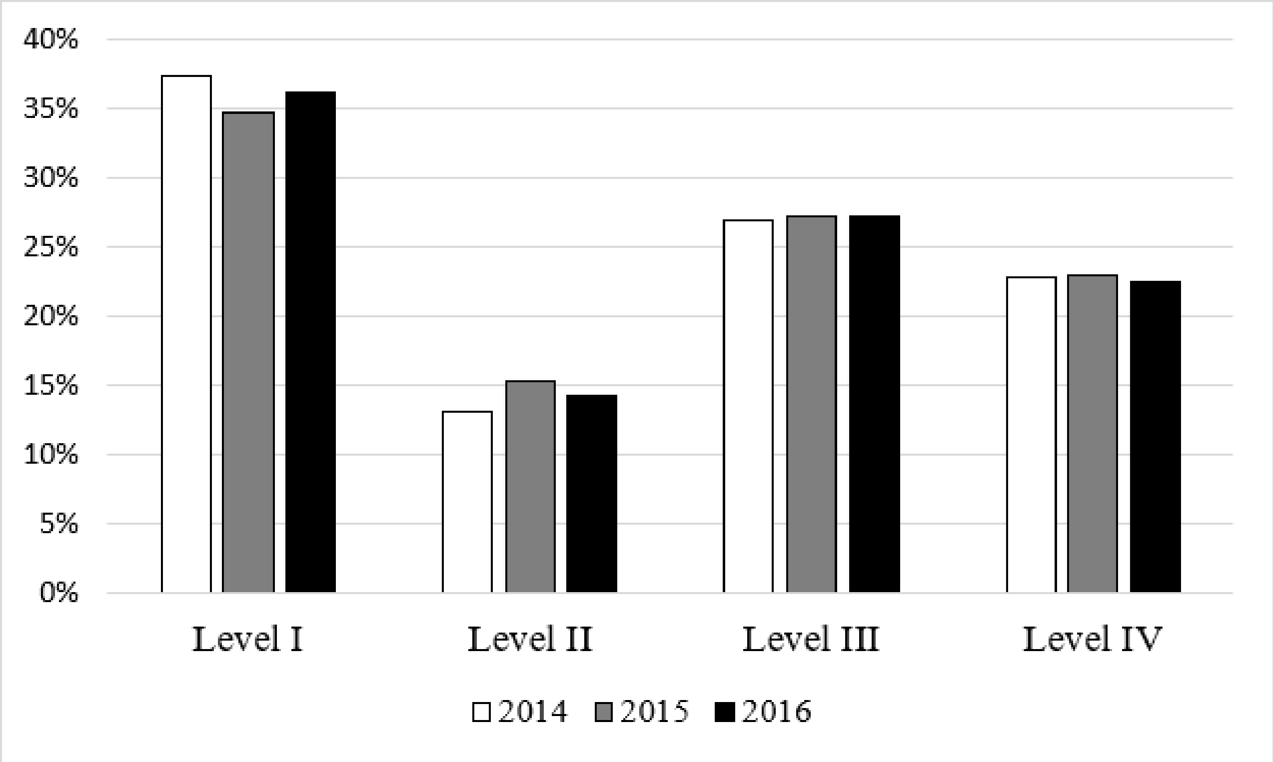

Figure 3. % of trauma injuries assisted by TCC level per year

- A total of 53 TCCs facilities included in the studied region.
- Four of those facilities are Level-I TCCs, three are Level-II TCCs, and the rest are Level-III and Level-IV.
- The results show that Level-I TCCs treat at least 35% of the trauma injuries per year

DESCRIPTIVE ANALYSIS RESULTS

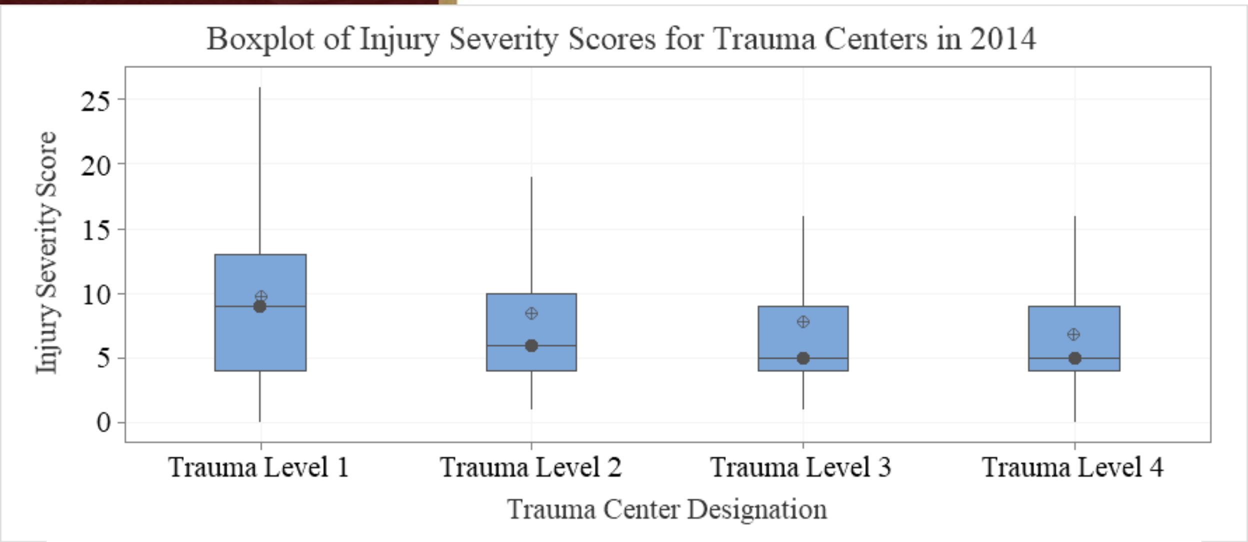

Figure 4. Injury severity scores per trauma level for 2014

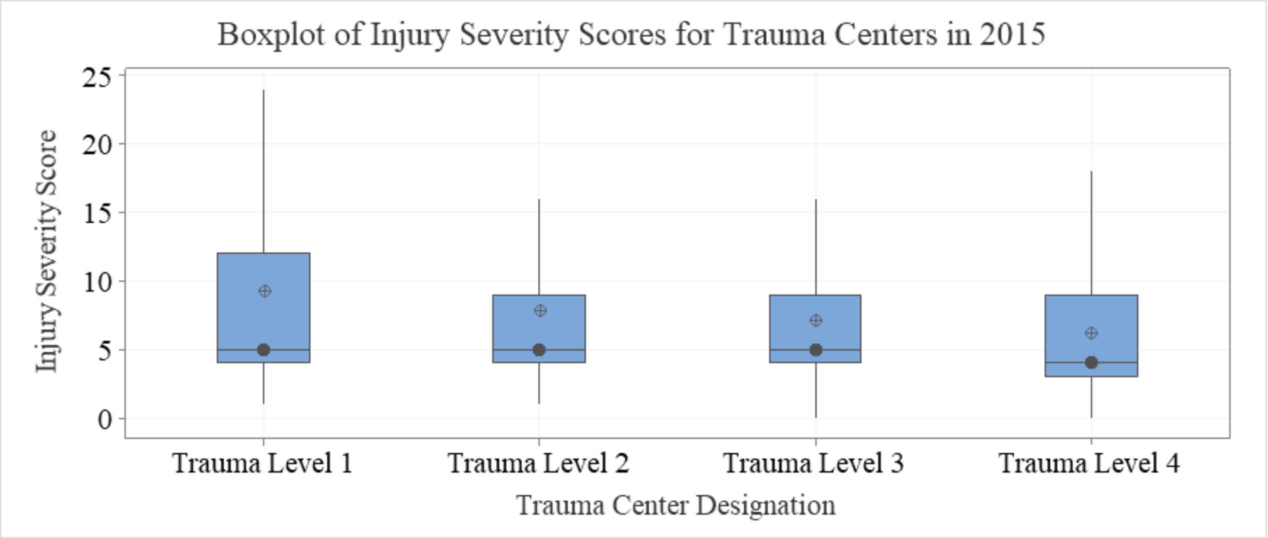

Figure 5. Injury severity scores per trauma level for 2015

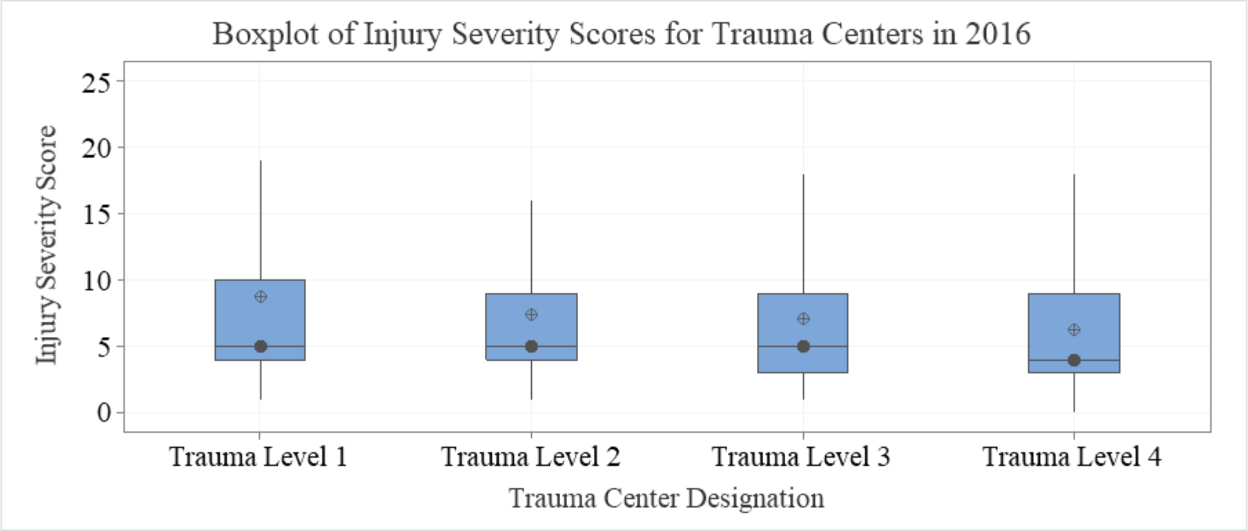

Figure 6. Injury severity scores per trauma level for 2016

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DESCRIPTIVE ANALYSIS RESULTS

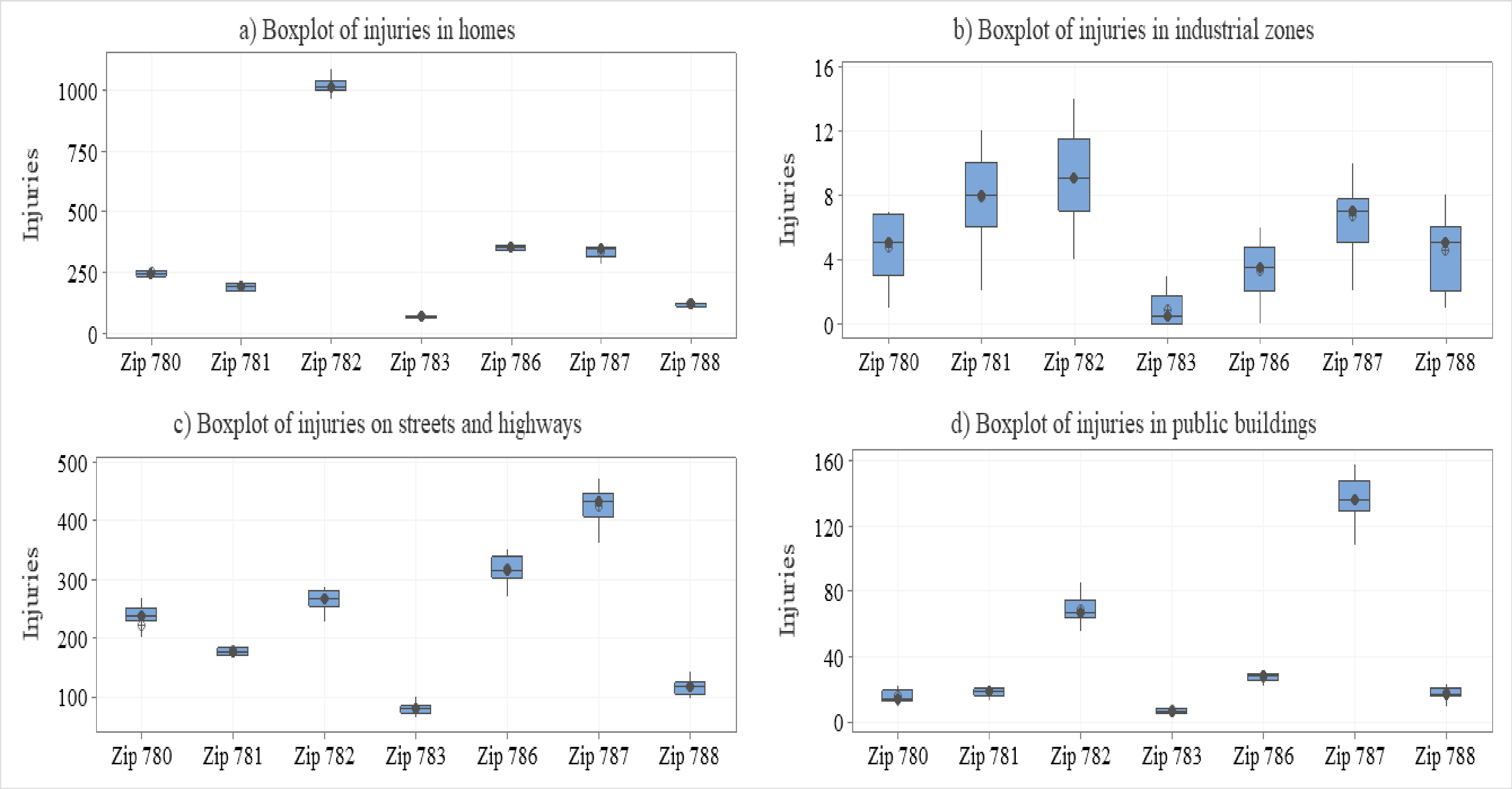
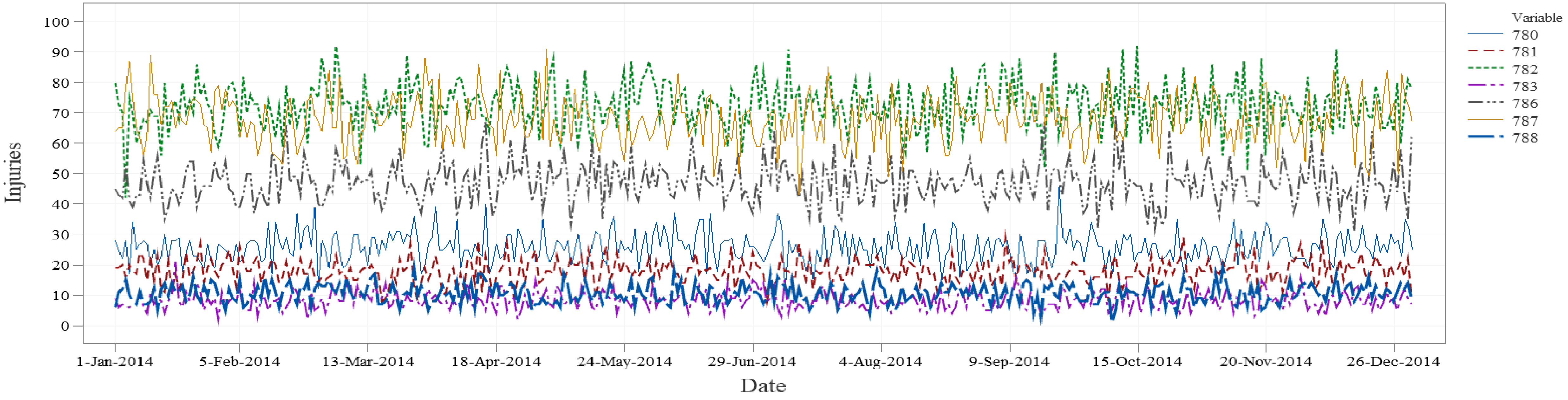


Figure 7. Injuries recorded by injury environment per regional location in 2014

FORECAST MODEL RESULTS



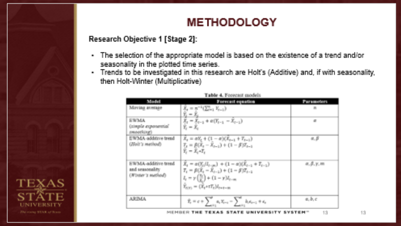


Table 6. MAPE results for 2014

Injury location	Moving average	EWMA (simple exponential smoothing)	EWMA-additive trend (Holt's method)	EWMA-additive trend and seasonality (Winter's method)	ARIMA
Injuries/Day	4.82	4.46	**4.45**	4.57	4.46
ZIP Code 780	17.88	16.40	16.39	16.65	**16.32**
ZIP Code 781	20.75	19.18	18.94	19.18	**18.91**
ZIP Code 782	9.53	**8.85**	8.89	9.10	8.88
ZIP Code 783	37.82	34.74	34.76	35.97	**34.64**
ZIP Code 786	12.63	11.28	11.30	11.93	**11.26**
ZIP Code 787	10.84	9.88	9.77	10.46	**9.76**
ZIP Code 788	32.15	30.66	30.57	31.45	**30.55**

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FORECAST MODEL RESULTS

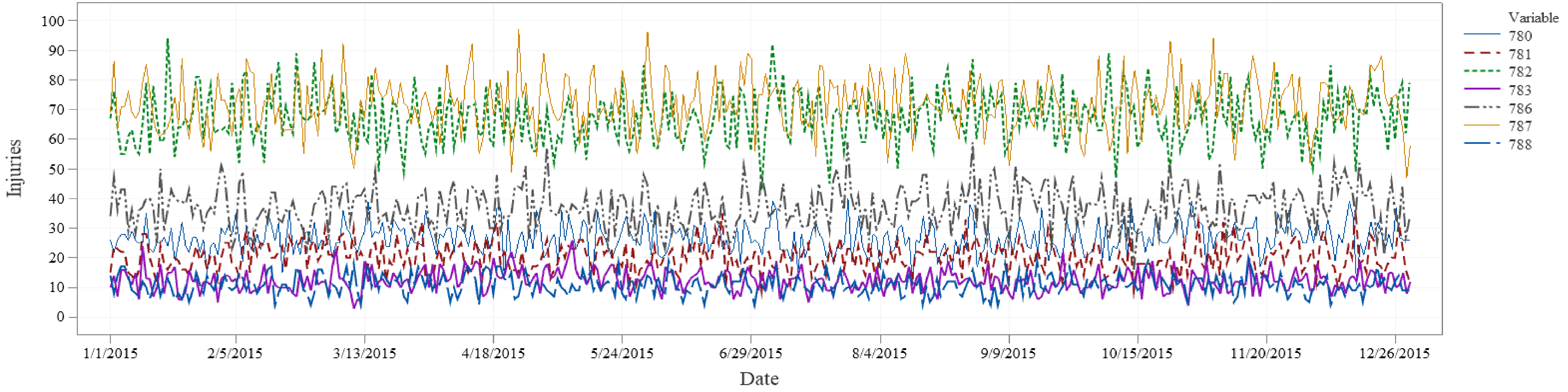

Table 7. MAPE results for 2015

Injury location	Moving average	EWMA (simple exponential smoothing)	EWMA-additive trend (Holt's method)	EWMA-additive trend and seasonality (Winter's method)	ARIMA
Injuries/Day	**6.00**	6.02	6.61	6.01	6.02
Zip Code 780	17.95	**16.28**	17.25	17.81	16.71
Zip Code 781	22.15	21.63	21.57	21.94	**21.32**
Zip Code 782	11.23	**10.51**	11.21	10.71	10.73
Zip Code 783	29.24	**27.83**	28.75	29.76	28.40
Zip Code 786	16.71	**16.06**	16.88	17.24	16.12
Zip Code 787	10.90	10.37	10.83	11.24	**10.31**
Zip Code 788	30.76	29.71	30.96	31.54	**29.47**

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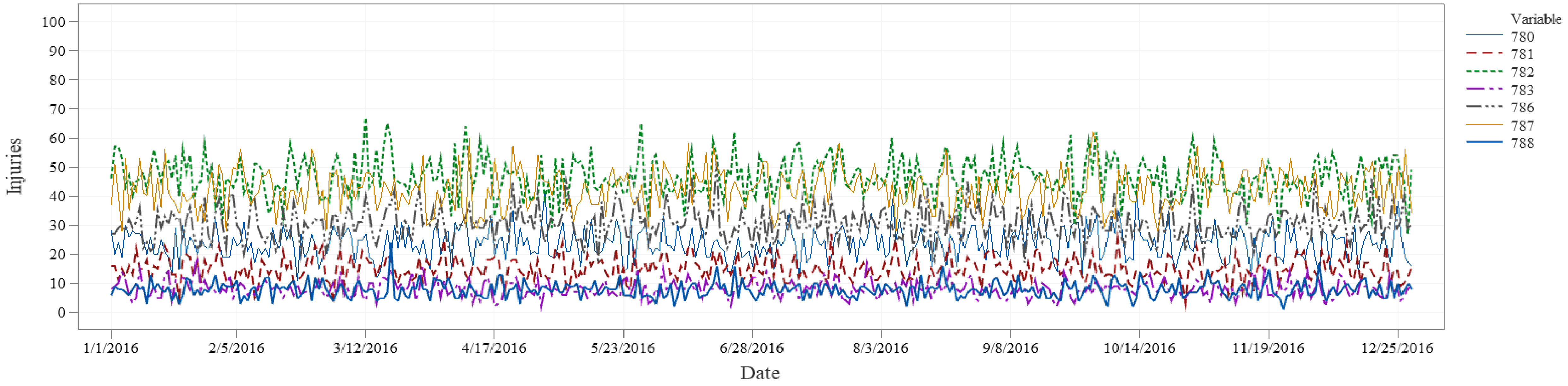
FORECAST MODEL RESULTS



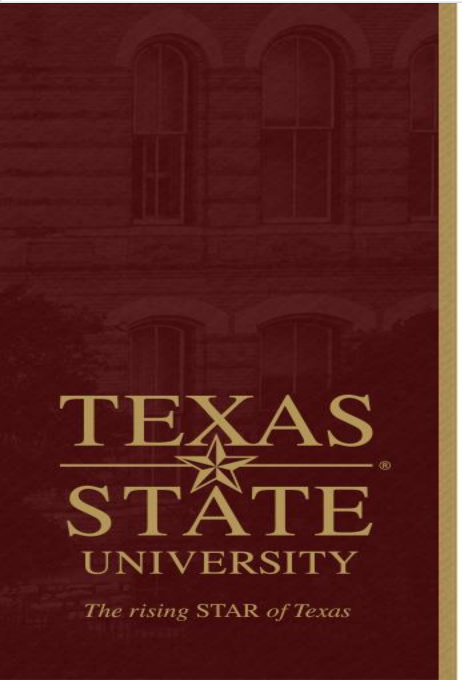


Table 8. MAPE results for 2016

Injury location	Moving average	EWMA (simple exponential smoothing)	EWMA-additive trend (Holt's method)	EWMA-additive trend and seasonality (Winter's method)	ARIMA
Injuries/Day	7.37	**7.30**	7.50	7.65	7.34
Zip Code 780	20.82	20.09	20.61	20.91	**20.09**
Zip Code 781	26.32	25.44	25.31	26.27	**25.11**
Zip Code 782	12.90	**12.35**	12.41	13.02	12.37
Zip Code 783	36.82	36.73	**36.21**	37.38	36.22
Zip Code 786	15.58	**14.53**	15.17	15.83	15.14
Zip Code 787	13.84	**13.68**	13.73	14.61	13.71
Zip Code 788	36.81	37.46	35.40	38.07	**35.34**

Research Objective 2

METHODOLOGY

Research Objective II

To develop a decision-making model for the Stochastic Trauma System Configuration Problem (STSCP)

Define the problem of expanding the current trauma network

Recommend which existing hospitals should consider become TCCs based on the forecasted number of injuries per zip codes in trauma region P

Clinical intervention is expected within an hour from the moment of an injury incident as a general rule of thumb

The travel times were computed using ArcGIS Pro which has a road network database, and the values are a result of calculations based on real time speed limits.

The distances from zip codes to hospitals (i.e. TCCs and non TCCs) were computed using geocoded centroids that represent the population for the zip code.

METHODOLOGY

Formulation :

- A two-stage programming model will be formulated to address the Stochastic Trauma System Model.

Table 1. Decision variables and parameters for proposed optimization model

Sets	
I	Set of injury demand nodes where $i \in I$ (patients in a geographical zone)
J	Set of eligible trauma center (TC) locations where $j \in J$
L	Set of trauma center levels $\ell \in L$
K	Set of eligible aeromedical depots (AD) locations where $k \in K$
N_i	$\{j \mid t_{ij}^G \leq S\}$ = TC sites within the time standard, S, of node i by ground
M_i	$\{(j,k) \mid t_{ki}^A + t_{ij}^A \leq S\}$ = (AD, TC) pairs within the time standard, S, of node i by air
First Stage Decision Variables	
$x_{j\ell}^{TC}$	=1 if a trauma center (TC) level ℓ is sited at node j, 0 otherwise
$x_{k\ell}^{AD}$	=1 if a heliport (AD) is sited at node k with a level ℓ trauma facility, 0 otherwise
$z_{kj\ell}$	=1 if an AD is sited at node k and a TC level ℓ is sited at node j , 0 otherwise
Second Stage Decision Variables	
$y_{i\ell}^{\omega}$	=1 if demand for level ℓ facility at node i under scenario ω is covered, 0 otherwise
$v_{i\ell}^{\omega}$	=1 if demand for level ℓ facility at node i under scenario ω is covered by ground, 0 otherwise
$u_{i\ell}^{\omega}$	=1 if demand for level ℓ facility at node i under scenario ω is covered by air, 0 otherwise
Parameters	
S	Time standard
p^{TC}	The number of TCs to be sited
p^{AD}	The number of ADs to be sited
t_{ij}^G	The driving time from node i to node j
t_{ij}^A	The flying time from node i to node j
t_{ki}^A	The flying time from node k to node i
$c_{j\ell}^{TC}$	Cost of opening a trauma center (TC) level ℓ is sited at node j
$c_{k\ell}^{AD}$	Cost of open an aeromedical depot (AD) is sited at node k with a level ℓ trauma facility
r	Number of trauma centers that can be place per level l
Stochastic Parameters	
$a_{i\ell}^{\omega}$	Population demand for a trauma center level ℓ at node i under scenario ω

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METHODOLOGY

$$\min \sum_{j\in J}\sum_{\ell\in L} c_{j\ell}\, x_{j\ell}^{TC} + \sum_{k\in J}\sum_{\ell\in L} c_{k\ell}\, x_{k\ell}^{AD} - \sum_{\omega\in\Omega} p_\omega * \{\sum_{i\in I}\sum_{\ell\in L} a_{i\ell}^{\omega} y_{i\ell}^{\omega}\} \quad (1a)$$

Subject to:

$$\sum_{j\in J}\sum_{\ell\in L} x_{j\ell}^{TC} \le p^{TC} \quad (1b)$$

$$\sum_{\ell\in L} x_{j\ell}^{TC} \le 1, \ \forall j \in J \quad (1c)$$

$$\sum_{k\in K}\sum_{\ell\in L} x_{k\ell}^{AD} \le p^{AD} \quad (1d)$$

$$\sum_{\ell\in L} x_{k\ell}^{AD} \le 1, \ \forall k \in K \quad (1e)$$

$$z_{kjl} - x_{j\ell}^{TC} \le 0, \ \forall j \in J, \ \forall k \in K, \forall \ell \in L \quad (1f)$$

$$z_{kjl} - x_{k\ell}^{AD} \le 0, \ \forall j \in J, \ \forall k \in K, \forall \ell \in L \quad (1g)$$

$$y_{i\ell}^{\omega} - v_{i\ell}^{\omega} - u_{i\ell}^{\omega} \le 0, \ \forall i \in I, \forall \ell \in L, \ \forall \omega \in \Omega \quad (1h)$$

$$v_{i\ell}^{\omega} - \sum_{j\in N_i} x_{j\ell}^{TC} \le 0, \ \forall i \in I, \forall \ell \in L, \ \forall \omega \in \Omega \quad (1i)$$

$$u_{i\ell}^{\omega} - \sum_{(j,k)\in M_i} z_{kj} \le 0, \ \forall i \in I, \forall \ell \in L, \ \forall j \in J, \ k \in K, \ \forall \omega \in \Omega \quad (1j)$$

$$\sum j \in J \quad x_{j\ell}^{TC} \le r, \ \forall \ell \in L \quad (1k)$$

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METHODOLOGY

Model Description

- Model objective: Maximize service coverage considering trauma network expansion
- Presence of facility at node to be indicated by 0 or 1.
- There is a maximum number of facilities that can be placed in a network.
- If a demand node is covered by a facility, based on the model, a hospital, it shall be denoted by 0 or 1.
- Travel times by air and ground will be placed in a set between facilities and demand nodes.
- Matrices, N_i and M_i, will be the data sets describing the travel times.

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EXPERIMENTATION

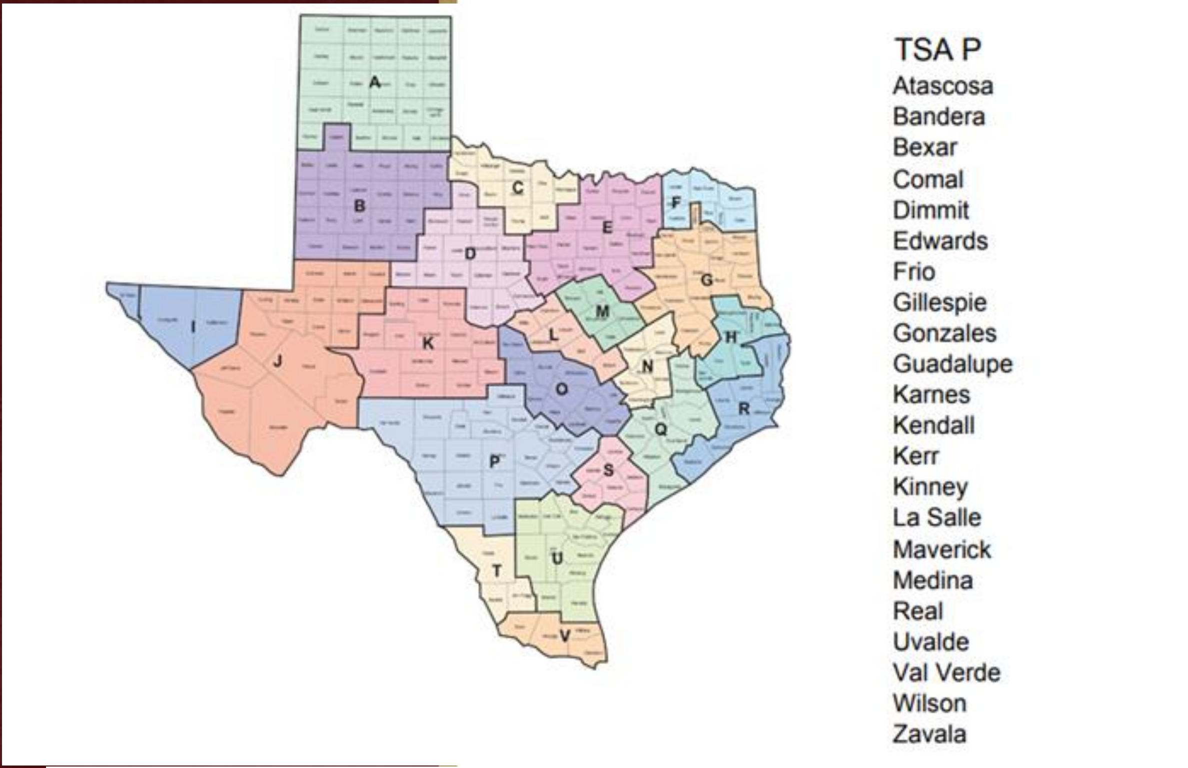


Figure 3. Regional Advisory Council, Trauma service areas and counties

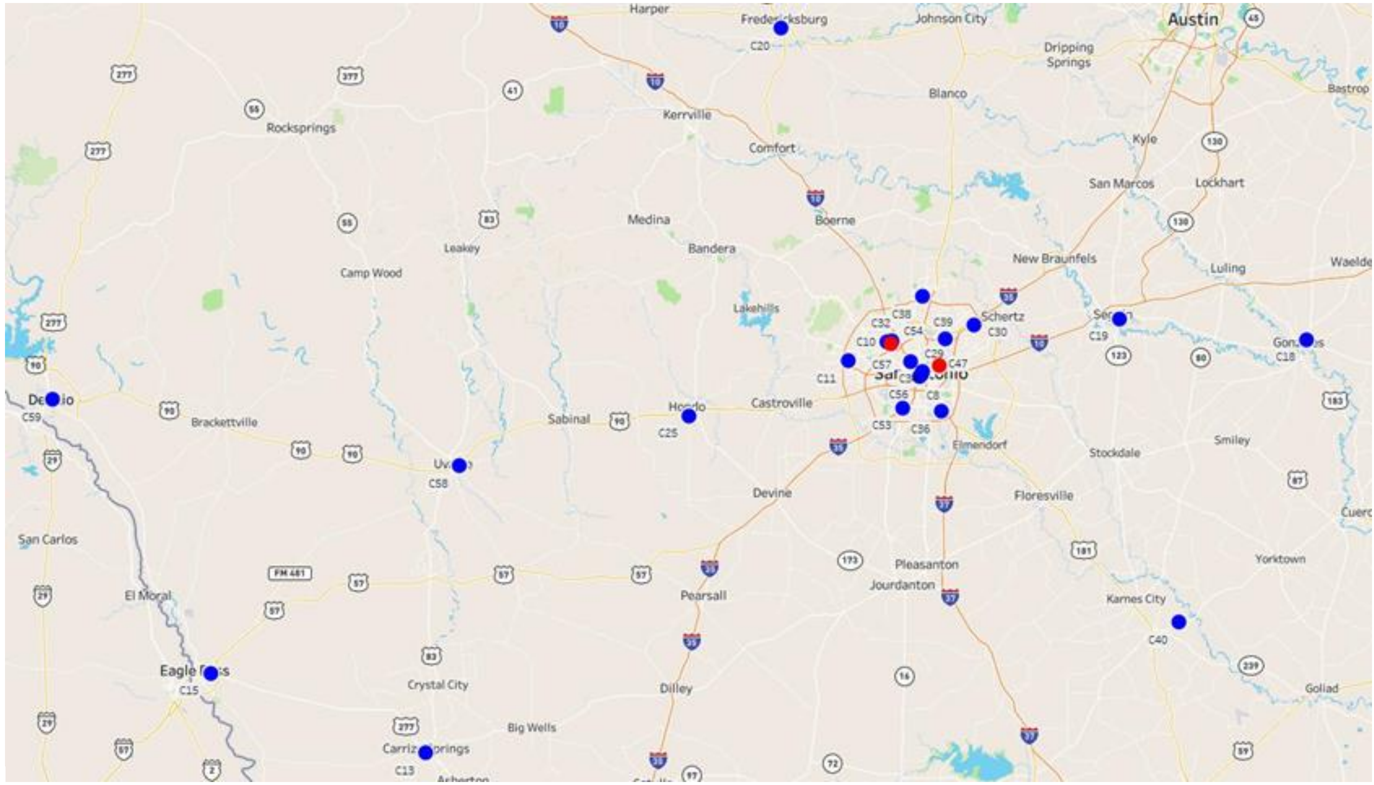
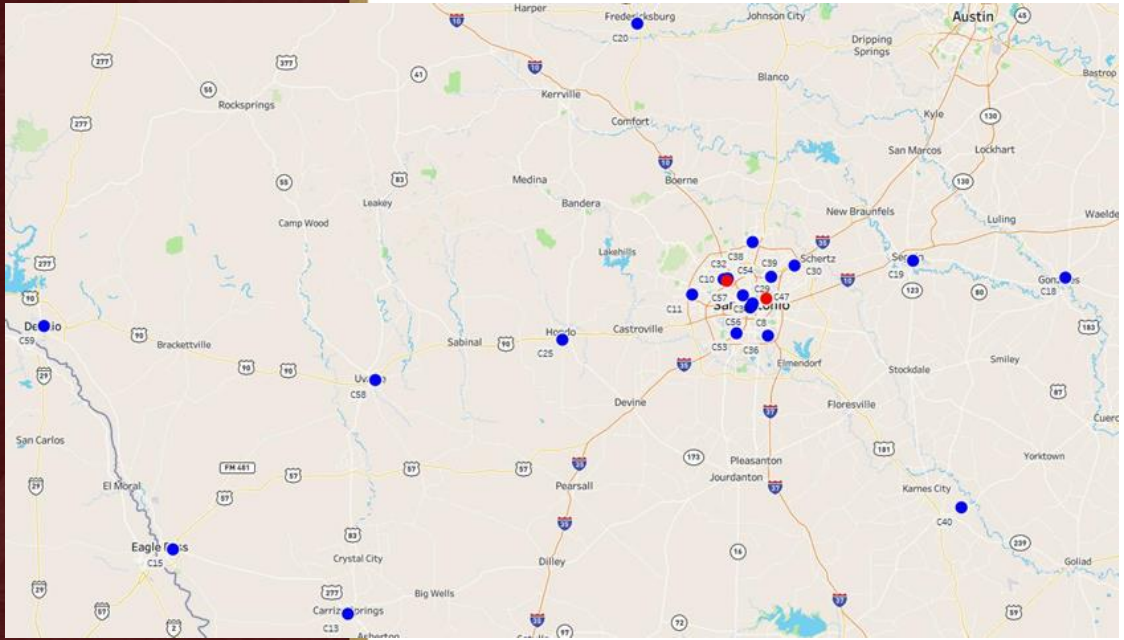
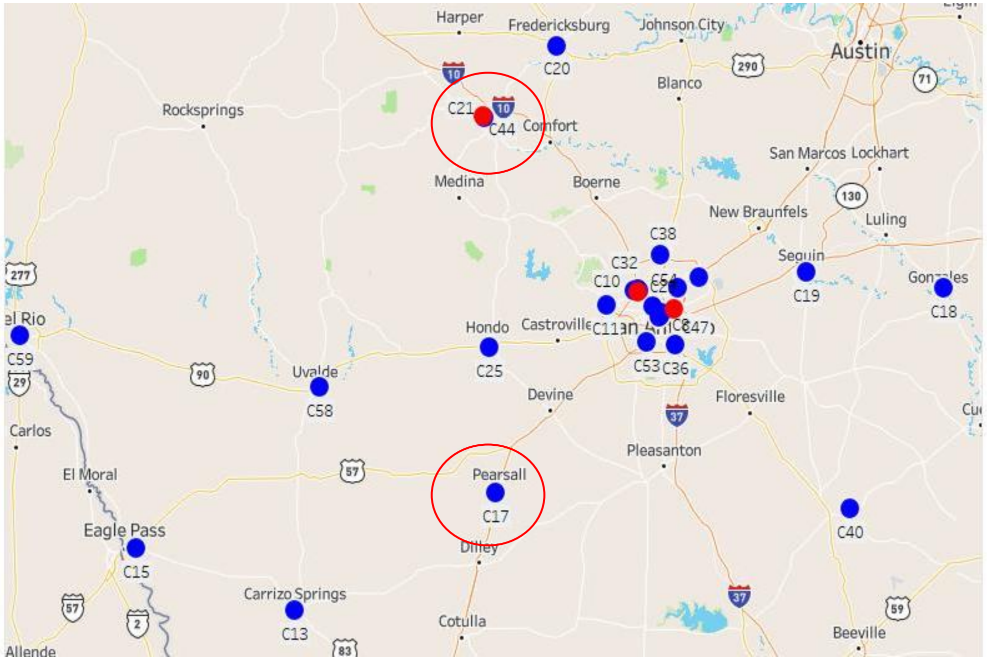
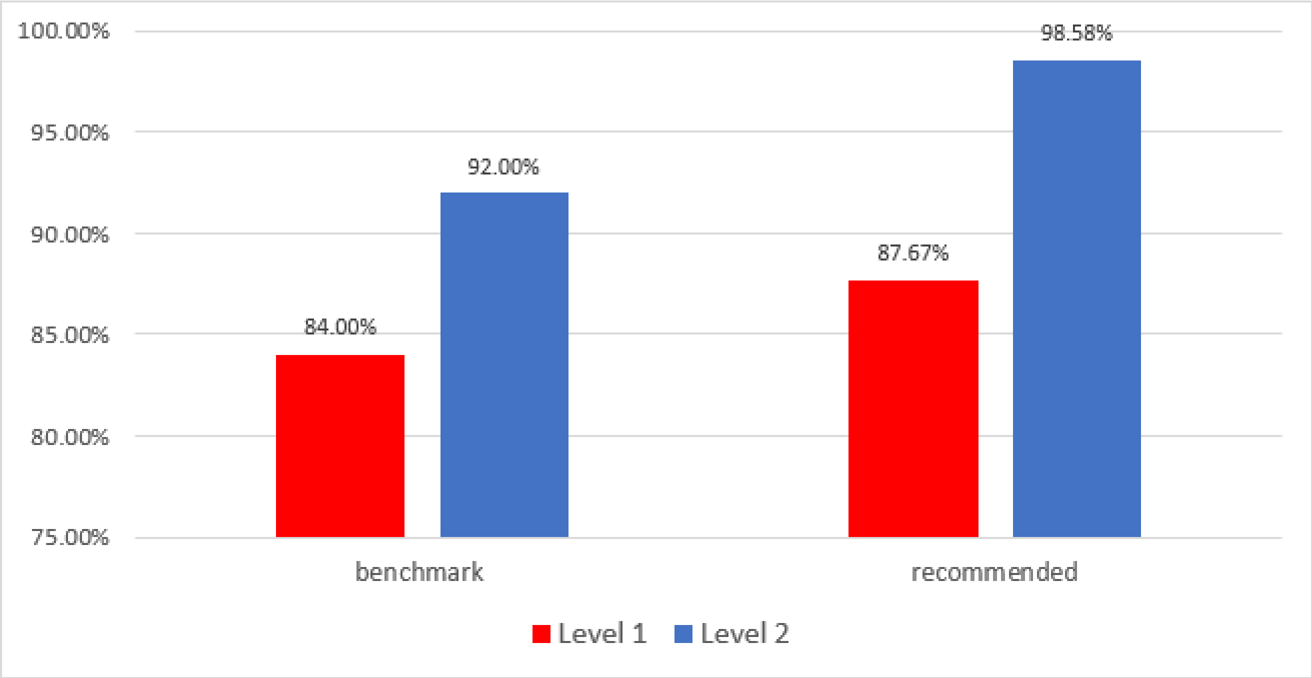


Figure 13 Trauma centers placed for Benchmark-System







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CONCLUSIONS

- Forecasting models can used to predict the number of patients that need trauma care based on varying scenarios.
- Forecasting models can be integrated to stochastic optimization decision making models to recommend trauma system expansion.
- The focus is to maximize access for citizens to TCCs in Texas
- Include scenarios which will analyse large scale natural disasters for similar circumstances and pandemics.

Questions?