Sta 440 Case 3

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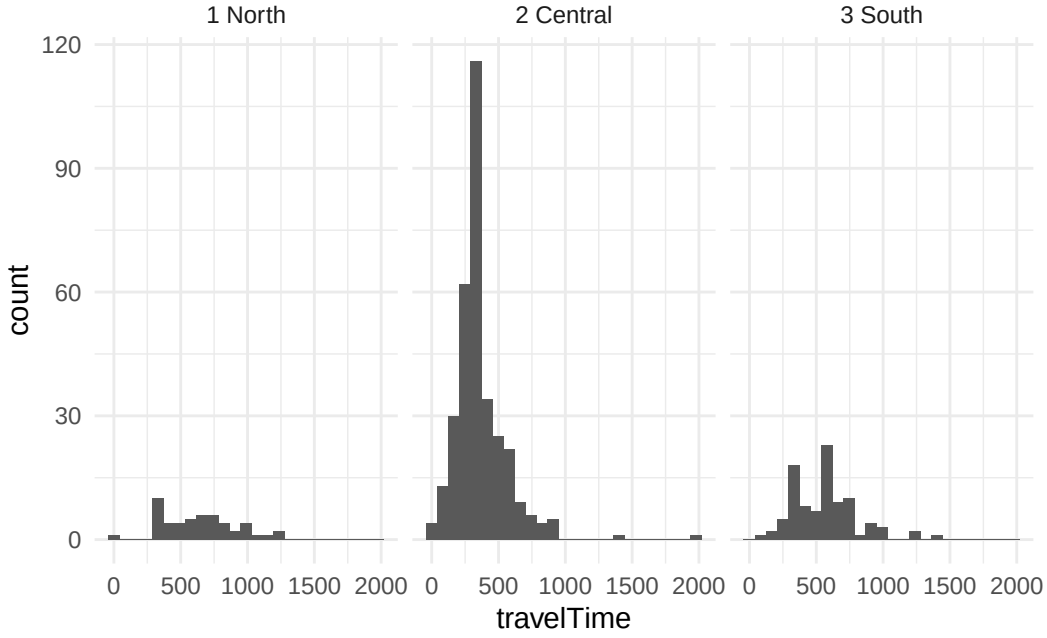
1. Background

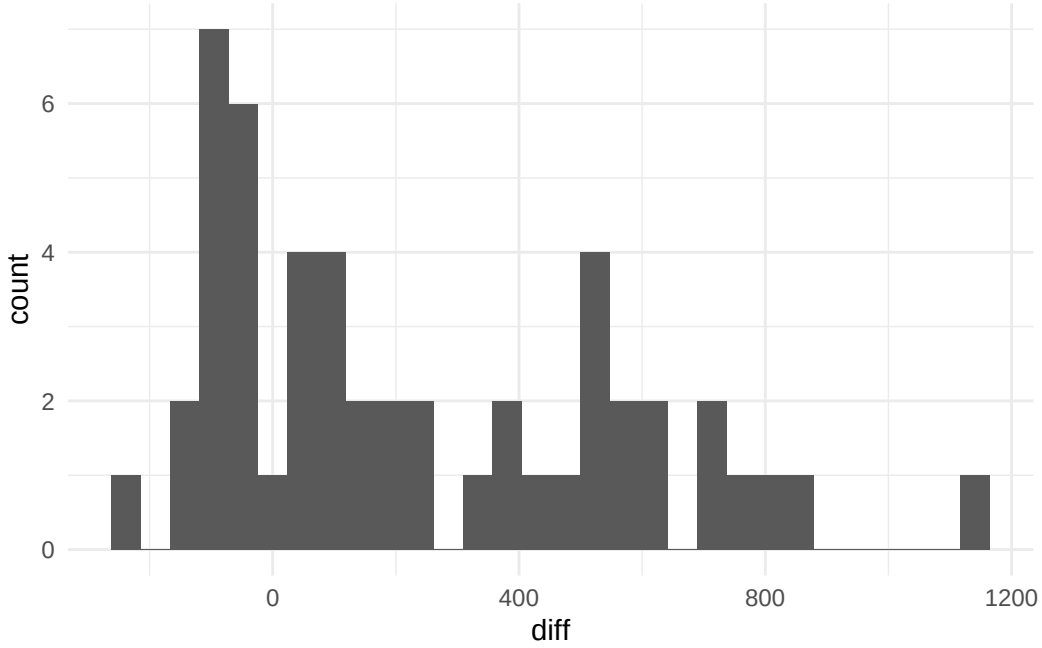
Emergency medical service (EMS) response times can drastically impact patient outcomes. Vance County, North Carolina is a growing county that is interested in evaluating their current EMS ambulance placements. The county has three major regions, the North, Central, and the South. The population is mostly concentrated in the city of Henderson, located in the Central region. There are currently 2 EMS stations, 1 in the South, and 1 in Central. The southern station has 1 ambulance, and the central station has 3. The north does not currently have a station. Thus Vance County is interested in exploring if moving an ambulance to the North would be beneficial. Finding the optimal locations for ambulances is vital because in the medical world EMS arriving seconds earlier can be the difference between life and death.

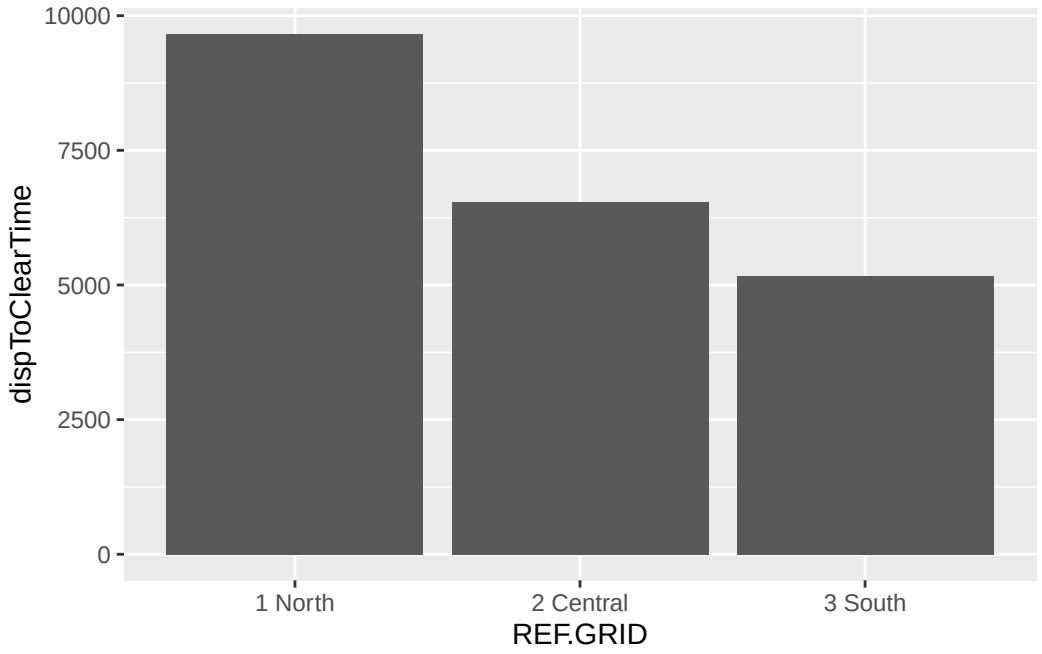
Research question: Where should the ambulances be stationed to best serve Vance county?

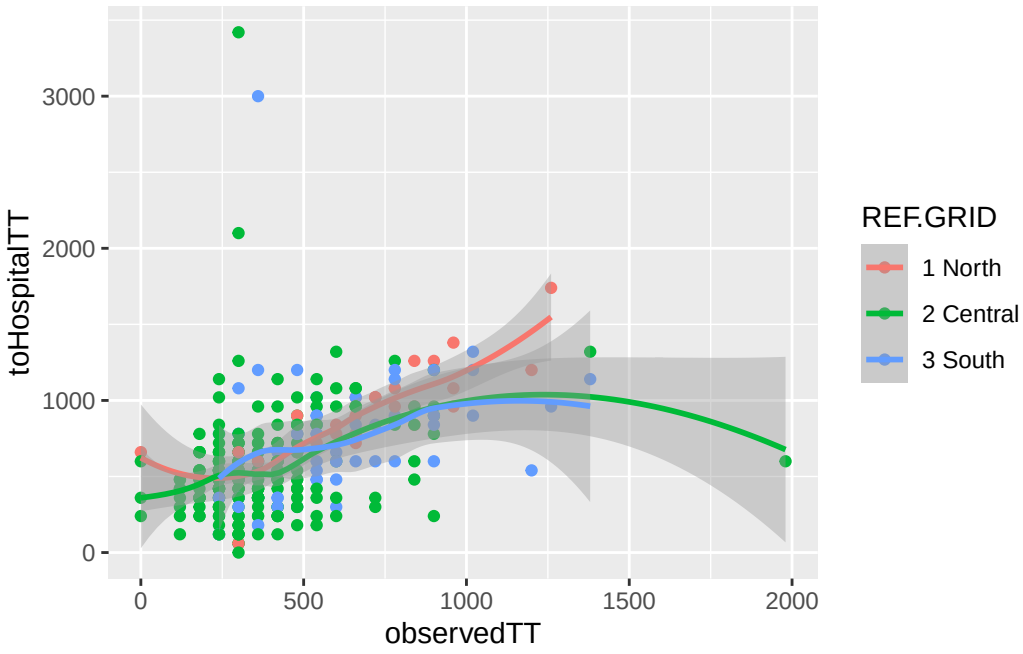
2. Data and Model Fit

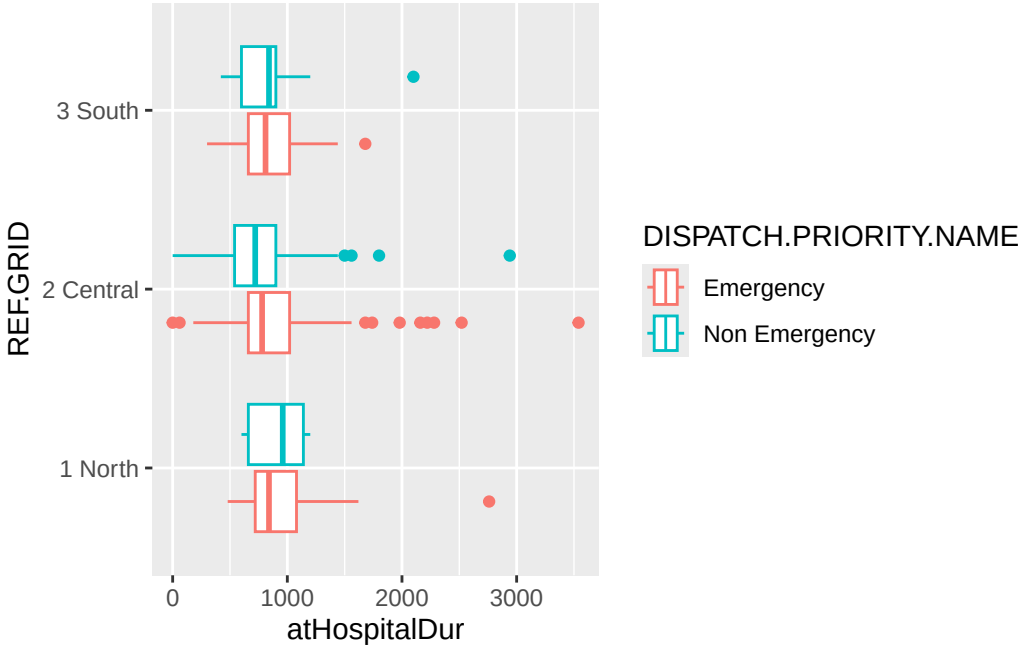
EMS calls with HIPAA protected details Each row is a call including: Arrival, dispatch, and enroute times Region and modified date Google Maps travel times from proposed and existing stations

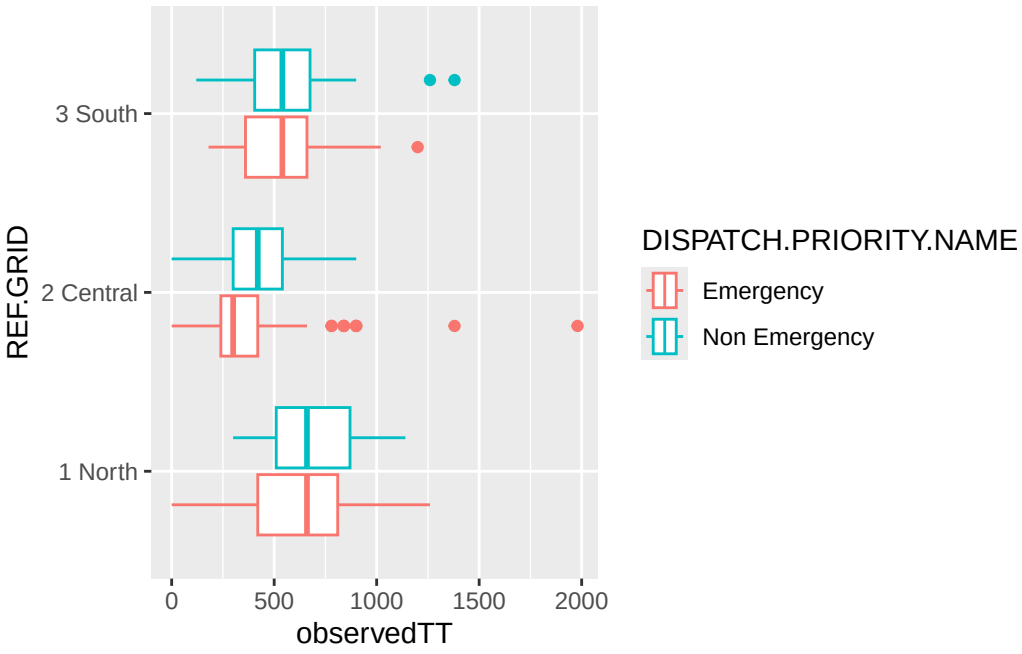



count
6
4
2
0
0
400
800
1200
diff

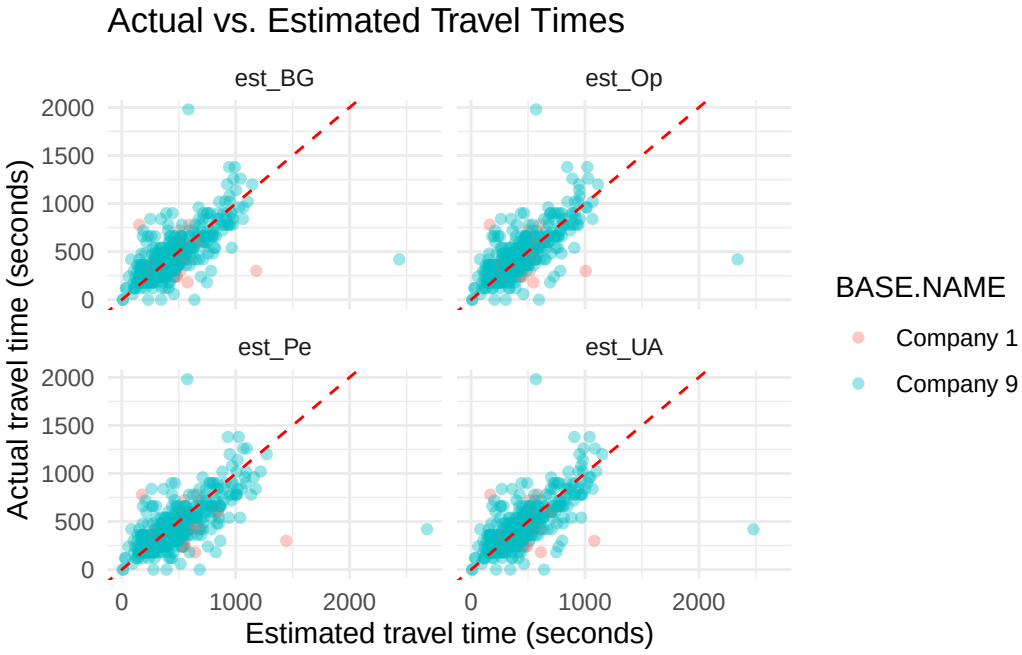

dispToClearTime
10000
7500
5000
2500
0
1 North
2 Central
3 South
REF.GRID

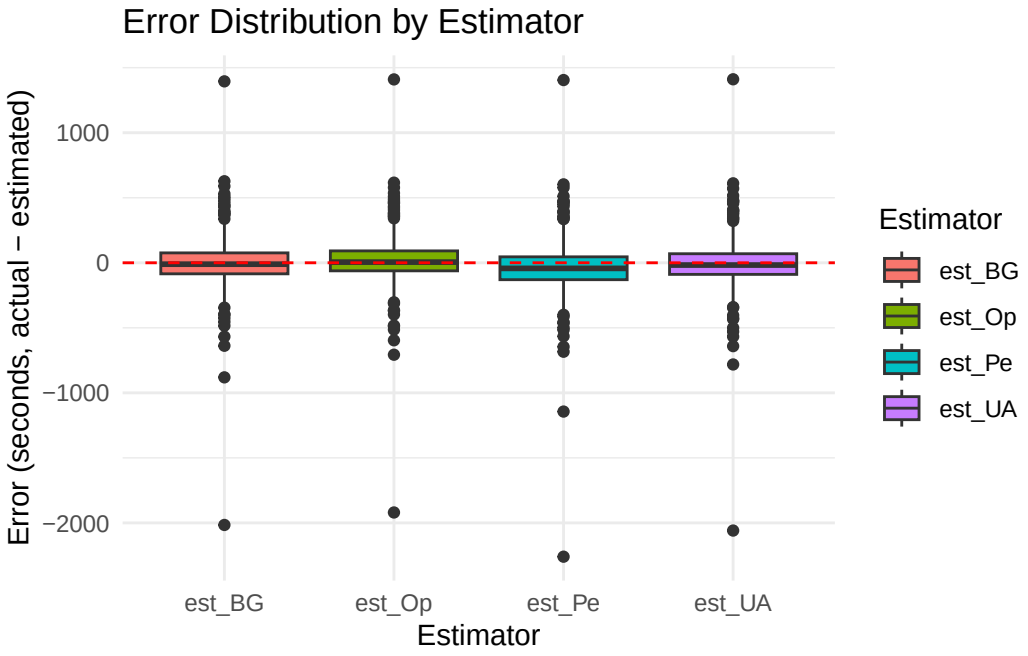

toHospitalTT
3000
2000
1000
0
0
500
1000
1500
2000
observedTT
REF.GRID
1 North
2 Central
3 South

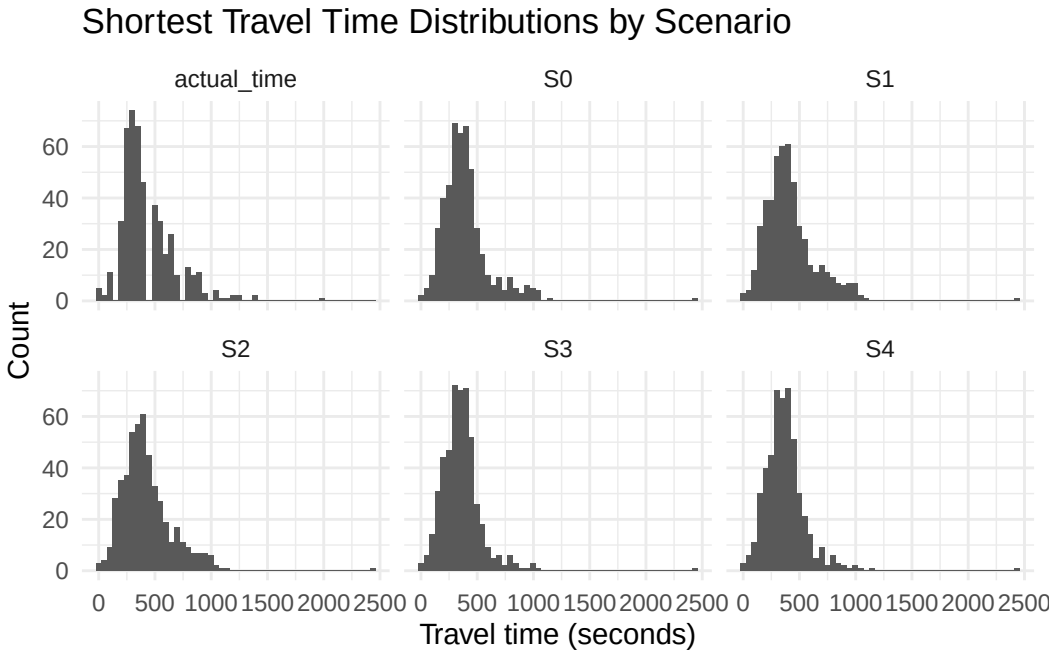

REF.GRID
3 South
2 Central
1 North
0
1000
2000
3000
atHospitalDur
DISPATCH.PRIORITY.NAME
Emergency
Non Emergency

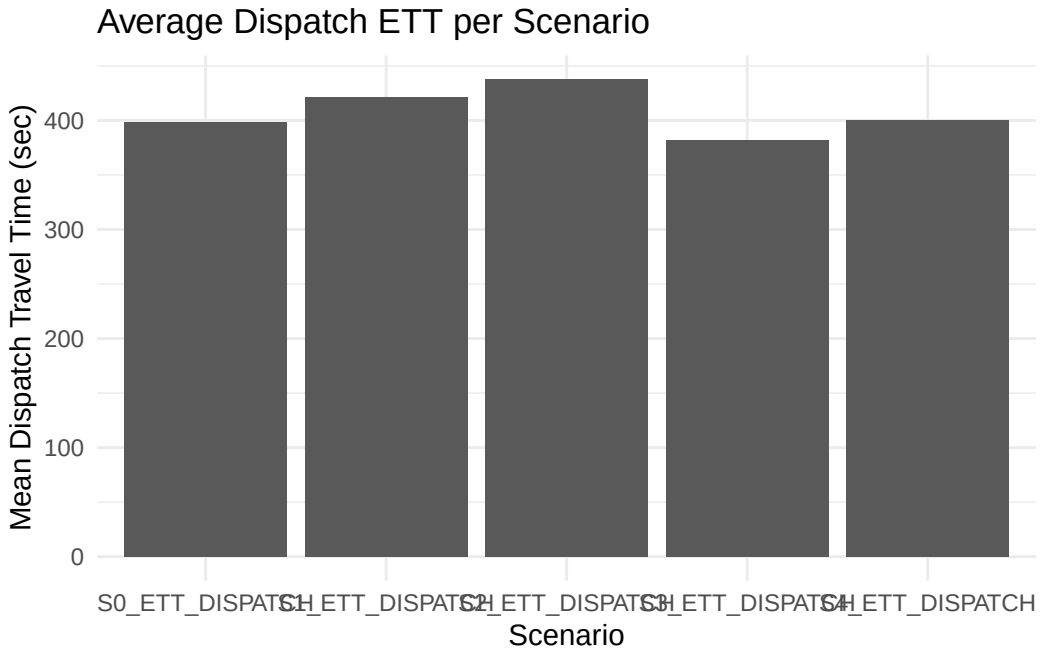


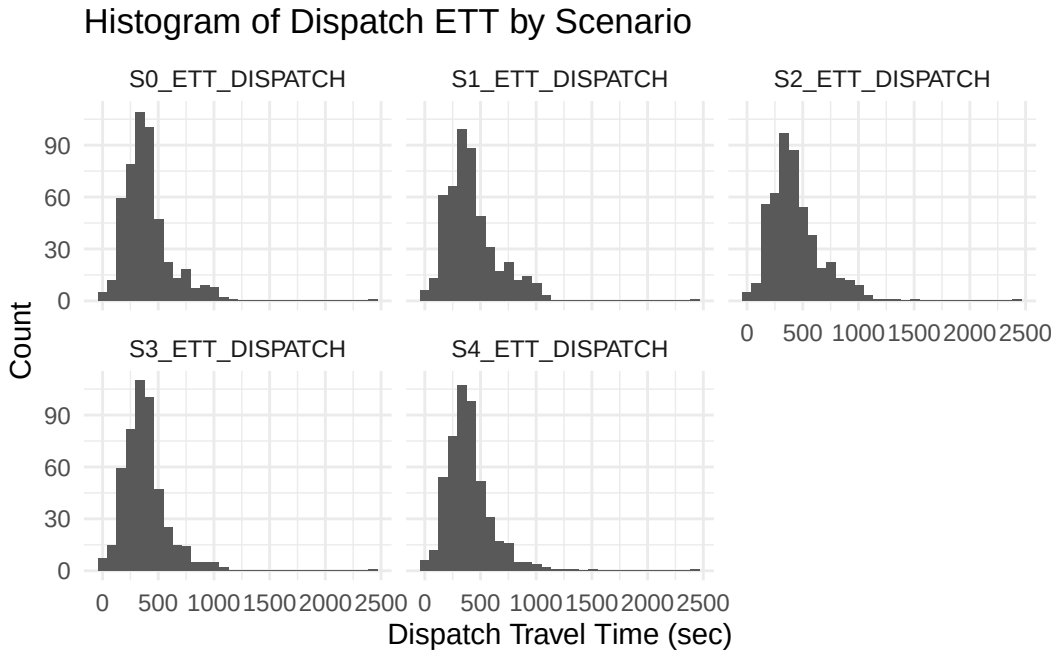

```
# A tibble: 4 x 4
  Estimator   MAE  RMSE   Bias
  <chr>     <dbl> <dbl>  <dbl>
1 est_BG     116.  192.  -1.74
2 est_Op     112.  186.  16.3
3 est_Pe     134.  214. -41.7
4 est_UA     116.  192.  -9.14
```




Error Distribution by Estimator
Error (seconds, actual − estimated)
1000
0
−1000
−2000
est_BG
est_Op
est_Pe
est_UA
Estimator
Estimator
est_BG
est_Op
est_Pe
est_UA

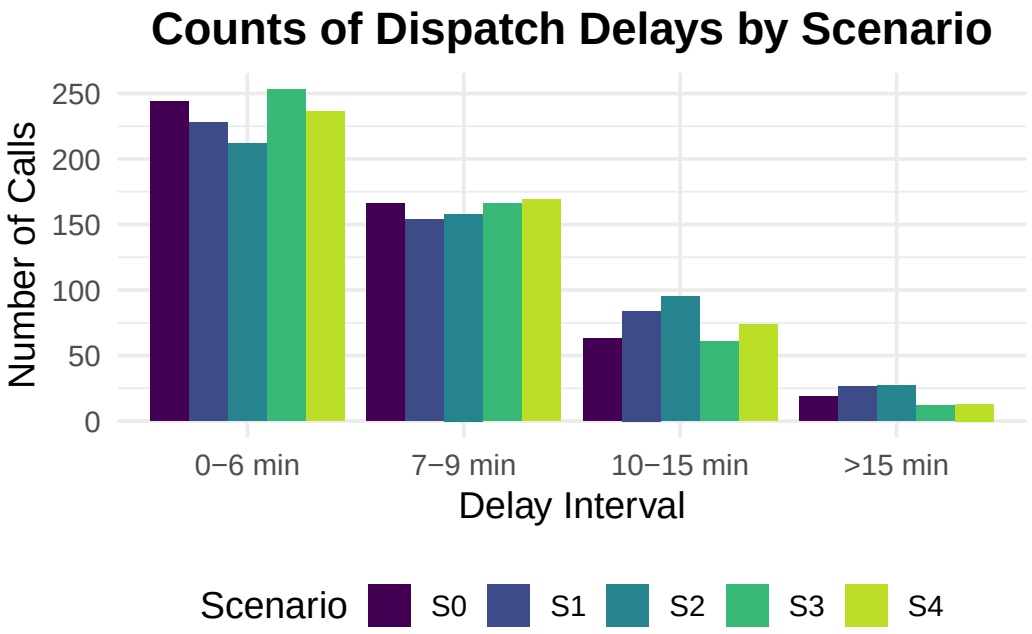

Shortest Travel Time Distributions by Scenario
actual_time
S0
S1
S2
S3
S4
Count
60
40
20
0
0
500
1000
1500
2000
2500
Travel time (seconds)

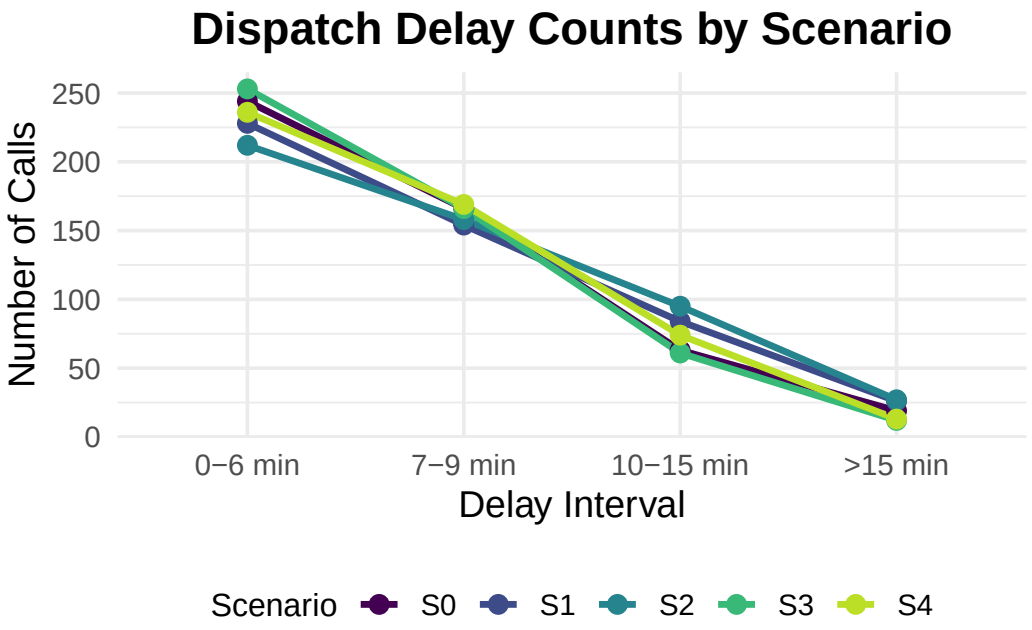


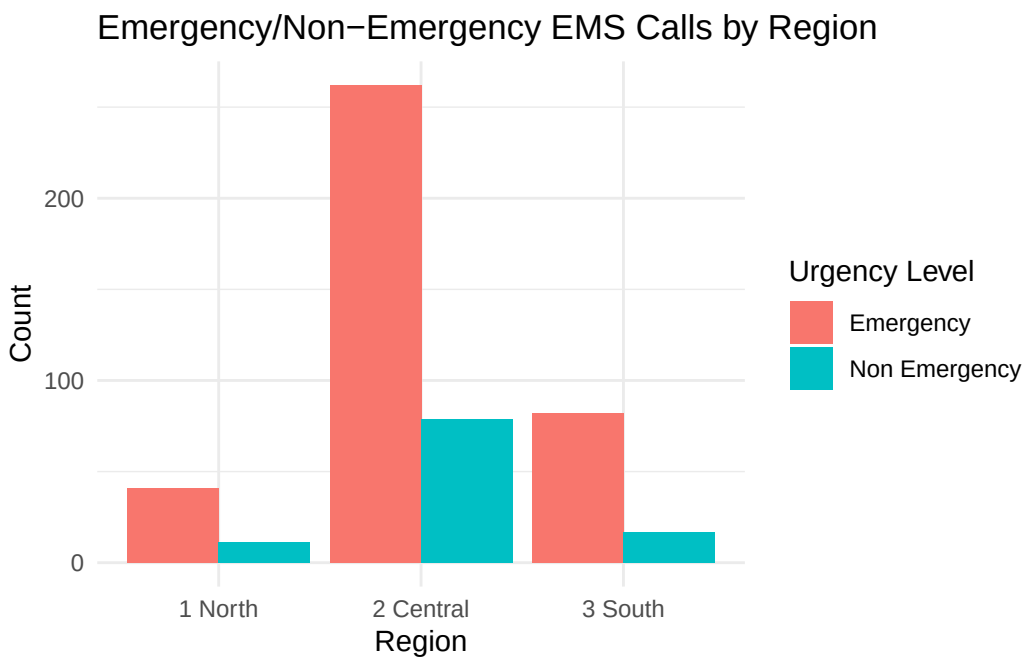



```
# A tibble: 20 x 3
   Scenario        DelayGroup     N
   <chr>           <fct>      <int>
 1 S0_ETT_DISPATCH 0-6 min      244
 2 S0_ETT_DISPATCH 7-9 min      166
 3 S0_ETT_DISPATCH 10-15 min     63
 4 S0_ETT_DISPATCH >15 min       19
 5 S1_ETT_DISPATCH 0-6 min      228
 6 S1_ETT_DISPATCH 7-9 min      154
 7 S1_ETT_DISPATCH 10-15 min     84
 8 S1_ETT_DISPATCH >15 min       26
```

```
 9 S2_ETT_DISPATCH 0-6 min      212
10 S2_ETT_DISPATCH 7-9 min      158
11 S2_ETT_DISPATCH 10-15 min     95
12 S2_ETT_DISPATCH >15 min       27
13 S3_ETT_DISPATCH 0-6 min      253
14 S3_ETT_DISPATCH 7-9 min      166
15 S3_ETT_DISPATCH 10-15 min     61
16 S3_ETT_DISPATCH >15 min       12
17 S4_ETT_DISPATCH 0-6 min      236
18 S4_ETT_DISPATCH 7-9 min      169
19 S4_ETT_DISPATCH 10-15 min     74
20 S4_ETT_DISPATCH >15 min       13
```



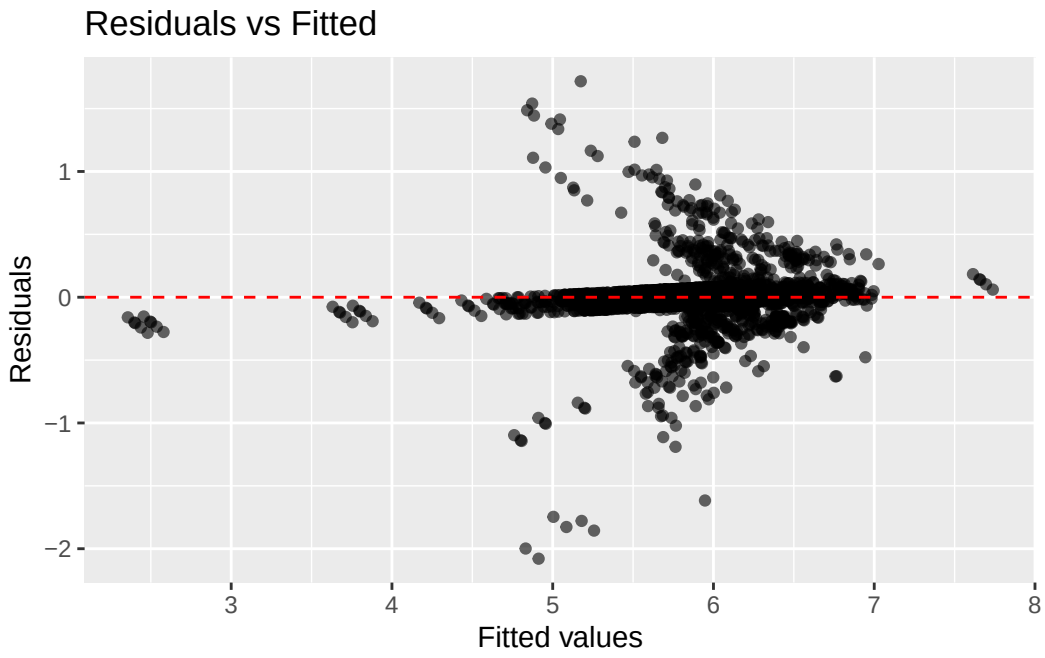


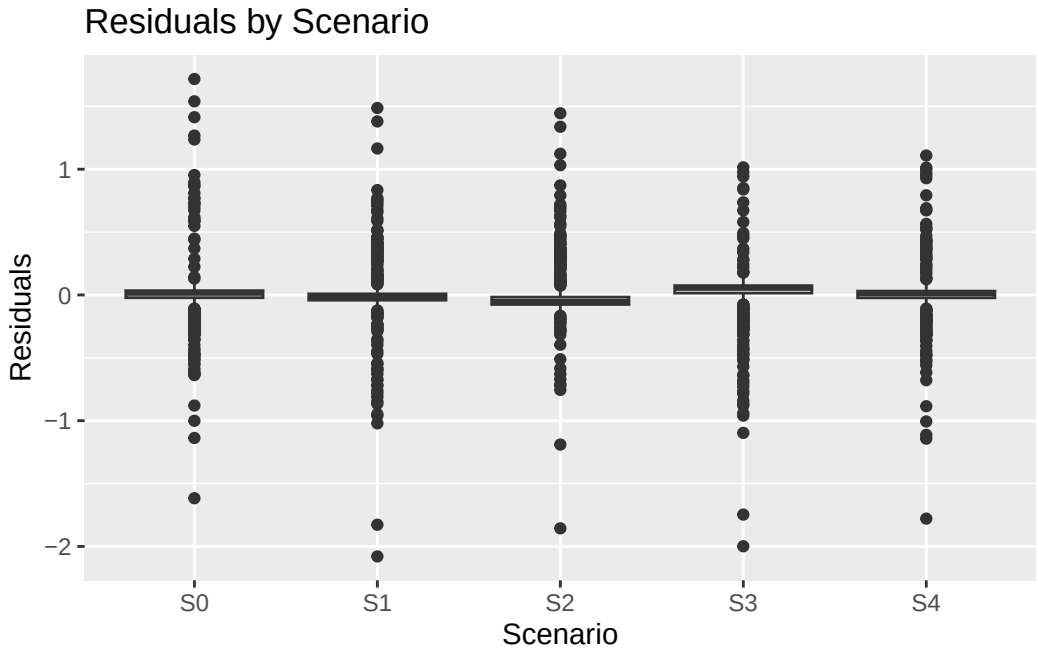


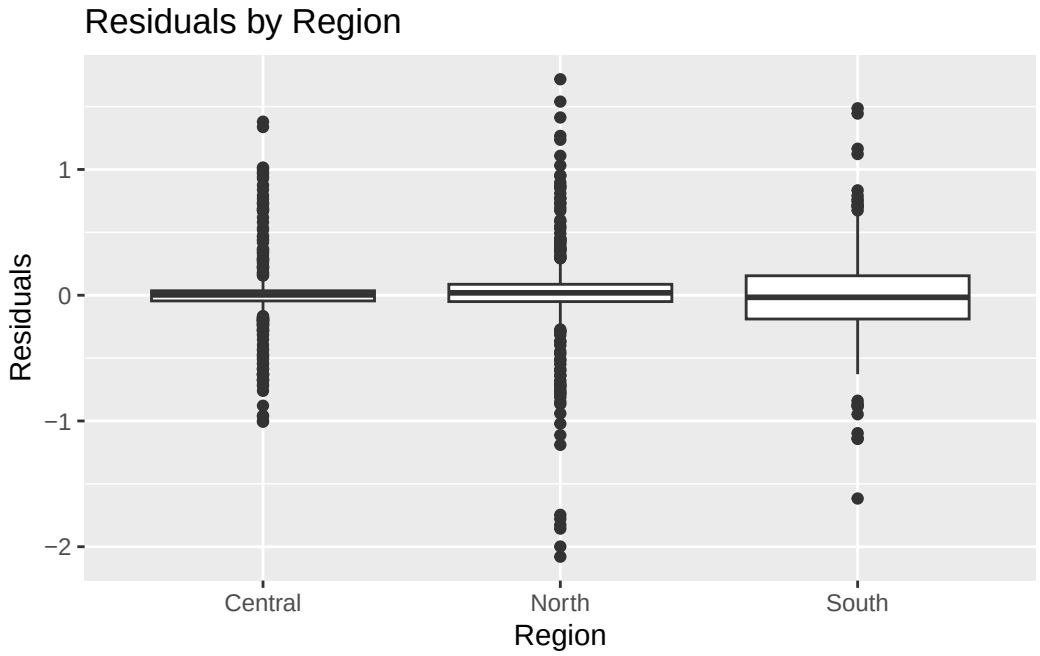

```
Linear mixed model fit by REML ['lmerMod']
Formula: obsTTmodified ~ (1 | REF.GRID) + DISPATCH.PRIORITY.NAME
   Data: x

REML criterion at convergence: 2560.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.9133 -0.5399 -0.2182  0.3473  7.6984

Random effects:
 Groups   Name        Variance Std.Dev.
 REF.GRID (Intercept)  5.617   2.370
 Residual              12.509   3.537
Number of obs: 476, groups:  REF.GRID, 3

Fixed effects:
                                  Estimate Std. Error t value
(Intercept)                          8.377      1.388   6.037
DISPATCH.PRIORITY.NAMENon Emergency   1.138      0.393   2.896

Correlation of Fixed Effects:
            (Intr)
DISPATCH.PE -0.059

Generalized least squares fit by REML
  Model: obsTTmodified ~ DISPATCH.PRIORITY.NAME
  Data: x
       AIC      BIC    logLik
```

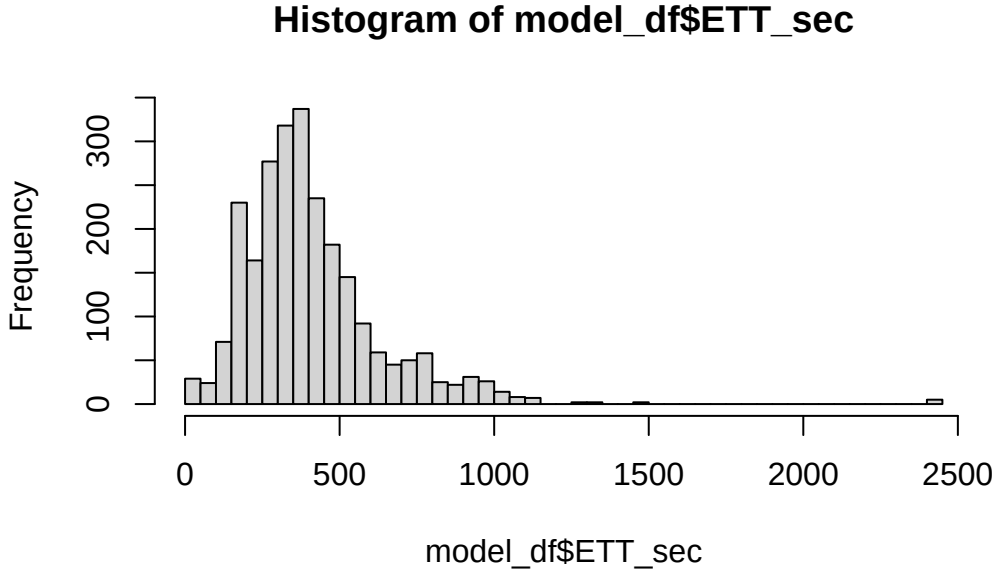
```
  2568.907 2585.552 -1280.454

Correlation Structure: Compound symmetry
 Formula: ~1 | region_category
 Parameter estimate(s):
      Rho
0.3098952

Coefficients:
                                     Value Std.Error  t-value p-value
(Intercept)                          8.377225  1.387607 6.037175   0.000
DISPATCH.PRIORITY.NAMENon Emergency 1.137910  0.392978 2.895608   0.004

 Correlation:
                                    (Intr)
DISPATCH.PRIORITY.NAMENon Emergency -0.059

Standardized residuals:
       Min         Q1        Med         Q3        Max
-2.2348794 -1.0281062 -0.5583537  0.1138833  5.7833057

Residual standard error: 4.257561
Degrees of freedom: 476 total; 474 residual


Call:
glm(formula = change_flag ~ region_category + DISPATCH.PRIORITY.NAME,
    family = binomial, data = model_df)

Coefficients:
                                   Estimate Std. Error z value Pr(>|z|)
(Intercept)                         -1.84130    0.07694 -23.933  < 2e-16 ***
region_categoryNorth                 1.86199    0.14458  12.878  < 2e-16 ***
region_categorySouth                 3.06905    0.12819  23.942  < 2e-16 ***
DISPATCH.PRIORITY.NAMENon Emergency -0.46880    0.13877  -3.378 0.000729 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 2965.4  on 2459  degrees of freedom
Residual deviance: 2188.6  on 2456  degrees of freedom
AIC: 2196.6

Number of Fisher Scoring iterations: 4

Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: log(ETT_sec) ~ Scenario + region_category + DISPATCH.PRIORITY.NAME +
```

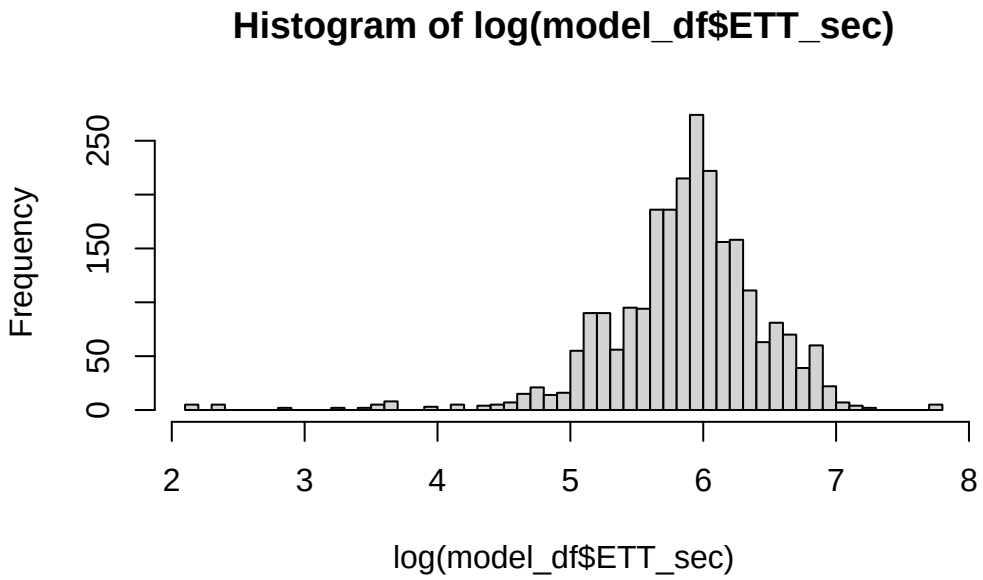
```
    (1 | row_val)
   Data: model_df

REML criterion at convergence: 2109.5

Scaled residuals:
    Min      1Q  Median      3Q     Max
-7.4455 -0.1945  0.0088  0.1643  6.1492

Random effects:
 Groups   Name        Variance Std.Dev.
 row_val  (Intercept) 0.23670  0.4865
 Residual             0.07798  0.2793
Number of obs: 2460, groups:  row_val, 492

Fixed effects:
                                    Estimate Std. Error         df t value
(Intercept)                          5.70728    0.03208  631.72338 177.925
ScenarioS1                           0.04018    0.01780 1964.00002   2.257
ScenarioS2                           0.08253    0.01780 1964.00002   4.636
ScenarioS3                          -0.04064    0.01780 1964.00002  -2.283
ScenarioS4                           0.00551    0.01780 1964.00002   0.309
region_categoryNorth                 0.37144    0.07479  487.99996   4.967
region_categorySouth                 0.44788    0.05744  487.99996   7.798
DISPATCH.PRIORITY.NAMENon Emergency  0.04280    0.05498  487.99996   0.778
                                   Pr(>|t|)
(Intercept)                         < 2e-16 ***
ScenarioS1                           0.0241 *
ScenarioS2                         3.79e-06 ***
ScenarioS3                           0.0226 *
ScenarioS4                           0.7570
region_categoryNorth               9.43e-07 ***
region_categorySouth               3.85e-14 ***
DISPATCH.PRIORITY.NAMENon Emergency  0.4367
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) ScnrS1 ScnrS2 ScnrS3 ScnrS4 rgn_cN rgn_cS
ScenarioS1  -0.278
ScenarioS2  -0.278  0.500
ScenarioS3  -0.278  0.500  0.500
ScenarioS4  -0.278  0.500  0.500  0.500
rgn_ctgryNr -0.314  0.000  0.000  0.000  0.000
rgn_ctgrySt -0.424  0.000  0.000  0.000  0.000  0.173
DISPATCH.PE -0.397  0.000  0.000  0.000  0.000  0.015  0.057
```

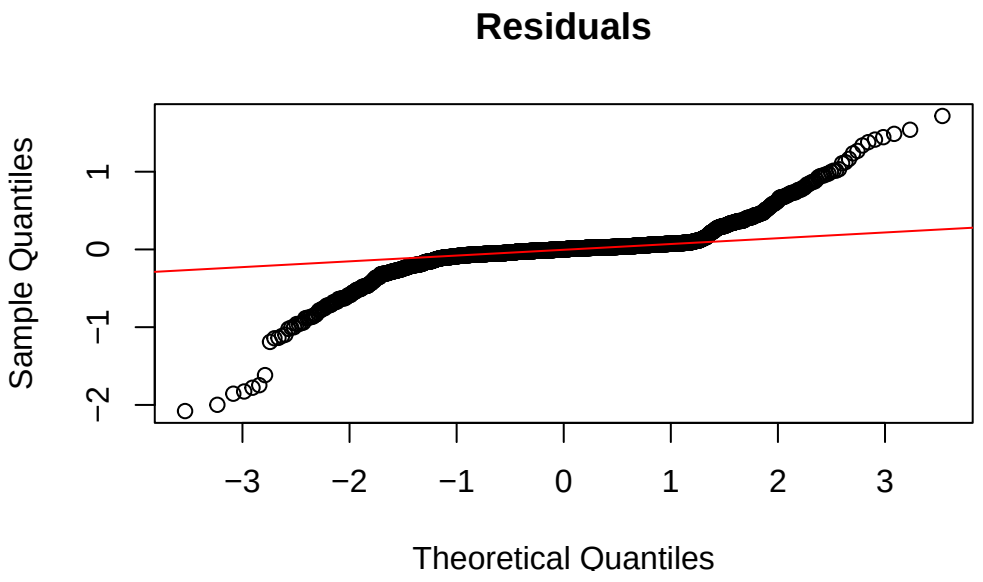

Residuals vs Fitted
Residuals
1
0
−1
−2
3
4
5
6
7
8
Fitted values

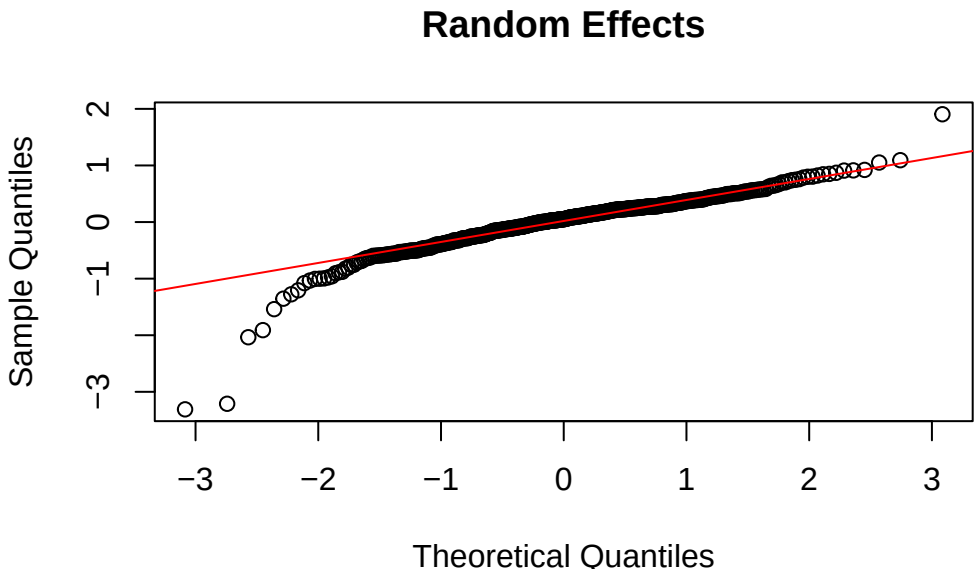

Residuals by Scenario
Residuals
1
0
−1
−2
S0
S1
S2
S3
S4
Scenario


Residuals by Region
Residuals
1
0
−1
−2
Central
North
South
Region


Histogram of model_df$ETT_sec
Frequency
0
100
200
300
0
500
1000
1500
2000
2500
model_df$ETT_sec

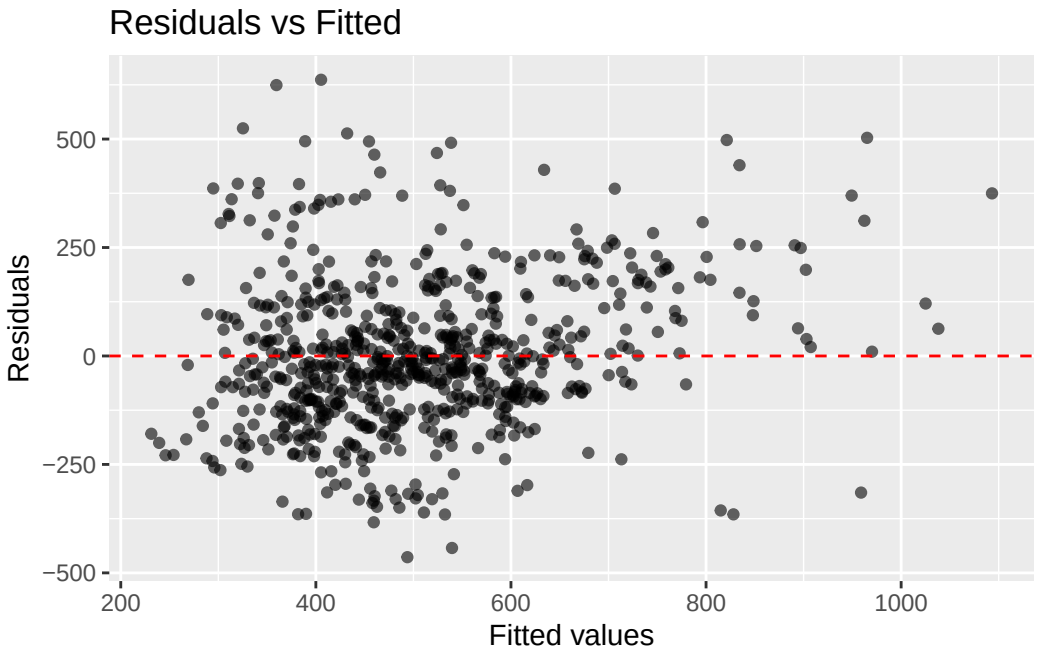

Histogram of log(model_df$ETT_sec)
Frequency
0
50
150
250
2
3
4
5
6
7
8
log(model_df$ETT_sec)

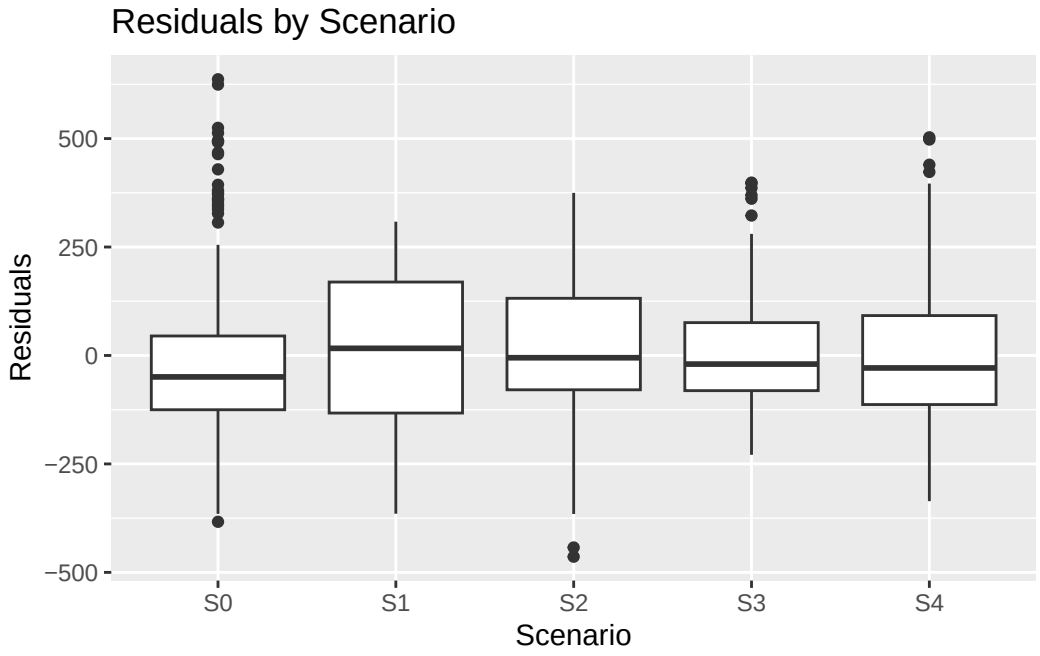

Residuals
Sample Quantiles
−2
−1
0
1
−3
−2
−1
0
1
2
3
Theoretical Quantiles

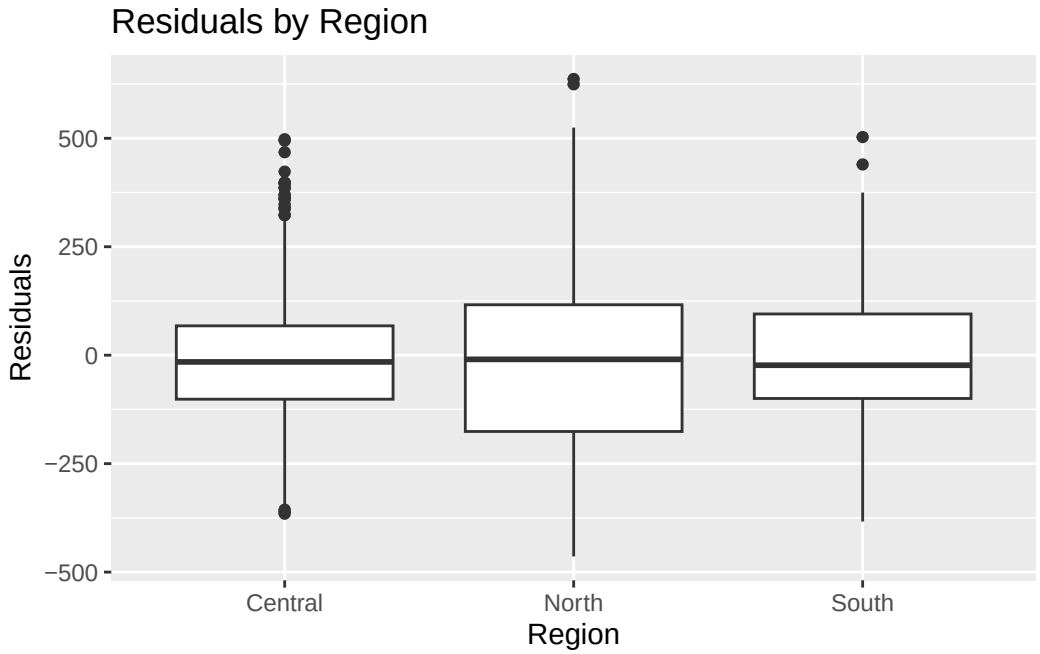


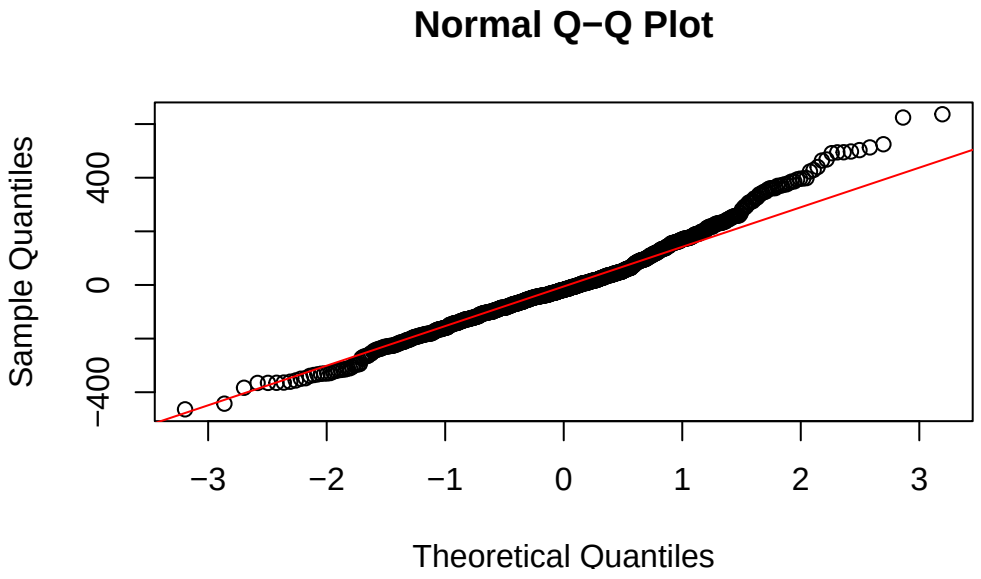

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: ETT_sec ~ Scenario + region_category + DISPATCH.PRIORITY.NAME +
    (1 | row_val)
   Data: changed_df

REML criterion at convergence: 9613

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.4866 -0.5641 -0.0985  0.5039  3.4132

Random effects:
 Groups   Name        Variance Std.Dev.
 row_val  (Intercept) 17449    132.1
 Residual             34793    186.5
Number of obs: 715, groups:  row_val, 143

Fixed effects:
                                  Estimate Std. Error      df t value
(Intercept)                        426.613     28.211 237.481  15.122
ScenarioS1                          79.252     22.059 568.000   3.593
ScenarioS2                         134.245     22.059 568.000   6.086
ScenarioS3                         -56.573     22.059 568.000  -2.565
ScenarioS4                           6.196     22.059 568.000   0.281
region_categoryNorth                -5.336     39.322 139.000  -0.136
region_categorySouth                72.876     29.886 139.000   2.438
DISPATCH.PRIORITY.NAMENon Emergency  46.085     35.611 139.000   1.294
                                  Pr(>|t|)
(Intercept)                        < 2e-16 ***
ScenarioS1                        0.000356 ***
```

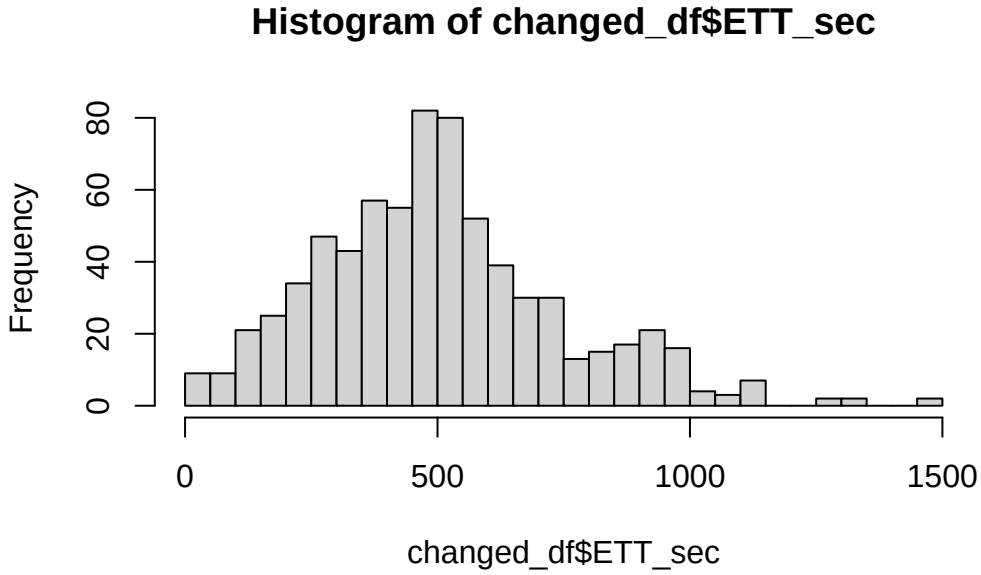
```
ScenarioS2                          2.14e-09 ***
ScenarioS3                          0.010585 *
ScenarioS4                          0.778913
region_categoryNorth                0.892265
region_categorySouth                0.016012 *
DISPATCH.PRIORITY.NAMENon Emergency 0.197760
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) ScnrS1 ScnrS2 ScnrS3 ScnrS4 rgn_cN rgn_cS
ScenarioS1  -0.391
ScenarioS2  -0.391  0.500
ScenarioS3  -0.391  0.500  0.500
ScenarioS4  -0.391  0.500  0.500  0.500
rgn_ctgryNr -0.520  0.000  0.000  0.000  0.000
rgn_ctgrySt -0.671  0.000  0.000  0.000  0.000  0.483
DISPATCH.PE -0.205  0.000  0.000  0.000  0.000  0.039 -0.013
```

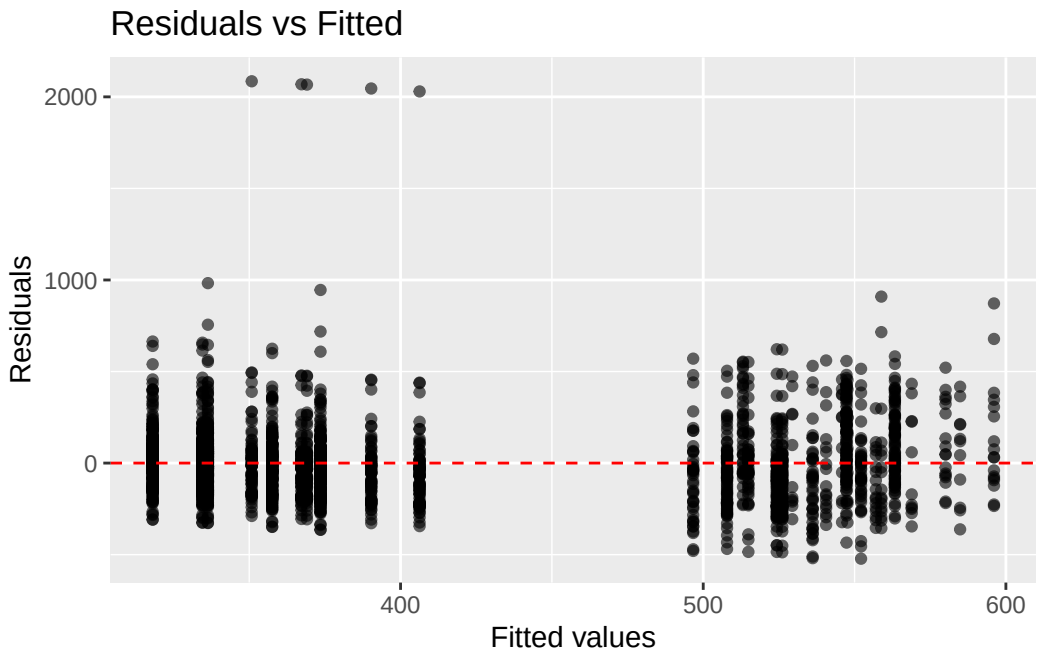


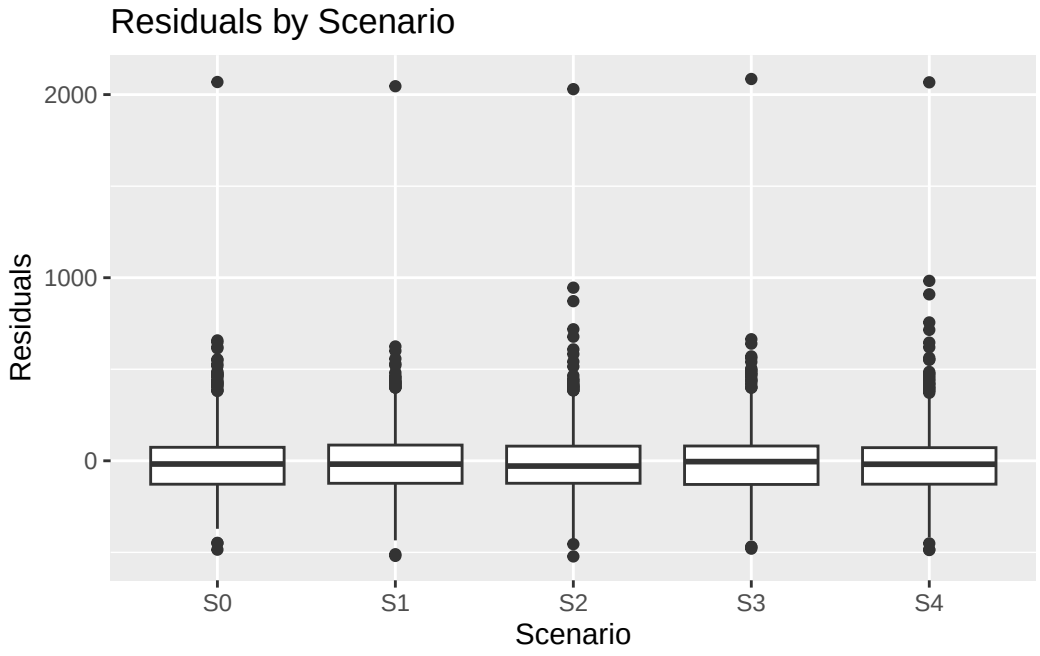

Residuals by Scenario
Residuals
500
250
0
−250
−500
S0
S1
S2
S3
S4
Scenario

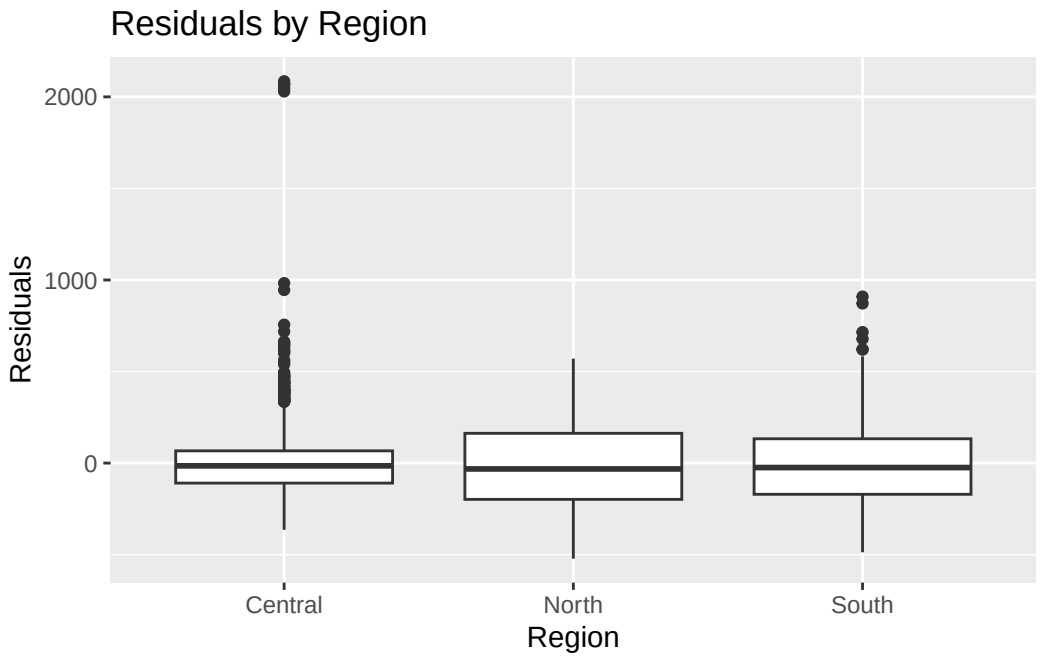

Residuals by Region
Residuals
500
250
0
−250
−500
Central
North
South
Region

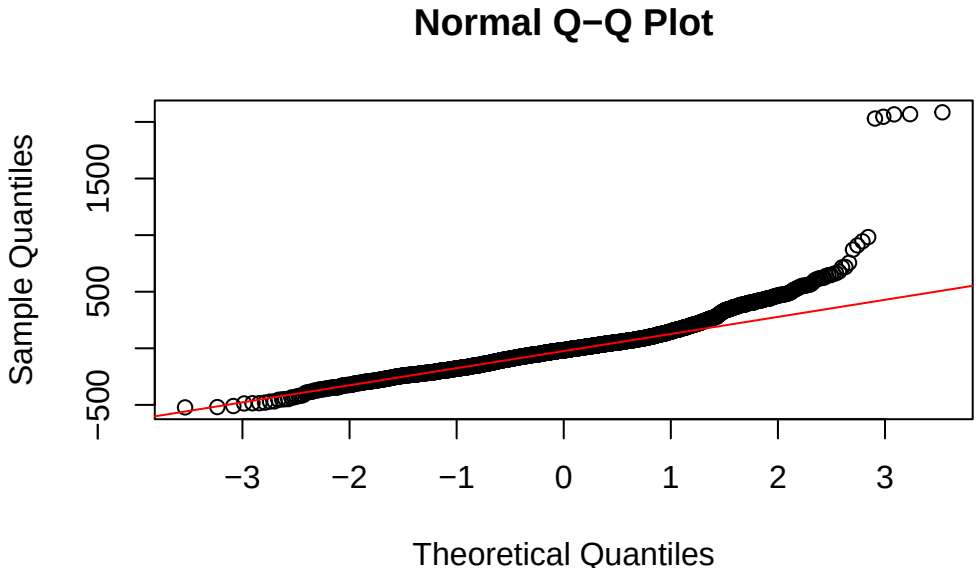

Normal Q−Q Plot
Sample Quantiles
400
0
−400
−3
−2
−1
0
1
2
3
Theoretical Quantiles


Histogram of changed_df$ETT_sec
Frequency
80
60
40
20
0
0
500
1000
1500
changed_df$ETT_sec


Residuals vs Fitted
2000
1000
0
Residuals
400
500
600
Fitted values


Residuals by Scenario
2000
1000
0
Residuals
S0
S1
S2
S3
S4
Scenario






```
                Model df      AIC      BIC    logLik   Test  L.Ratio p-value
gls_model           1  9 33214.66 33266.90 -16598.33
gls_model_region    2 19 32977.35 33087.57 -16469.67 1 vs 2 257.3084  <.0001

              Model df      AIC      BIC    logLik   Test  L.Ratio p-value
gls_model         1  9 33214.66 33266.90 -16598.33
gls_model_pow     2 18 32954.17 33058.59 -16459.08 1 vs 2 278.4893  <.0001

Type III Analysis of Variance Table with Satterthwaite's method
                      Sum Sq Mean Sq NumDF DenDF F value    Pr(>F)
Scenario              4.2186 1.05465     4  1964 13.5242 7.053e-11 ***
region_category       5.7932 2.89661     2   488 37.1447 9.644e-16 ***
DISPATCH.PRIORITY.NAME 0.0472 0.04725     1   488  0.6059    0.4367
---
```

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
          df      AIC
lmm_model 10  2129.54
gls_model  9 33214.66
```

```
          df       BIC
lmm_model 10  2187.619
gls_model  9 33266.898
```

```
Type III Analysis of Variance Table with Satterthwaite's method
                      Sum Sq Mean Sq NumDF DenDF F value    Pr(>F)
Scenario              4.2186 1.05465     4  1964 13.5242 7.053e-11 ***
region_category       5.7932 2.89661     2   488 37.1447 9.644e-16 ***
DISPATCH.PRIORITY.NAME 0.0472 0.04725     1   488  0.6059    0.4367
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
              df      AIC
lmm_model     10  2129.54
gls_model_pow 18 32954.17
```

```
              df       BIC
lmm_model     10  2187.619
gls_model_pow 18 33058.592
```

```
Type III Analysis of Variance Table with Satterthwaite's method
                       Sum Sq Mean Sq NumDF DenDF F value Pr(>F)
Scenario               3177443  794361     4   568 22.8310 <2e-16 ***
region_category         284976  142488     2   139  4.0953 0.0187 *
DISPATCH.PRIORITY.NAME   58272   58272     1   139  1.6748 0.1978
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

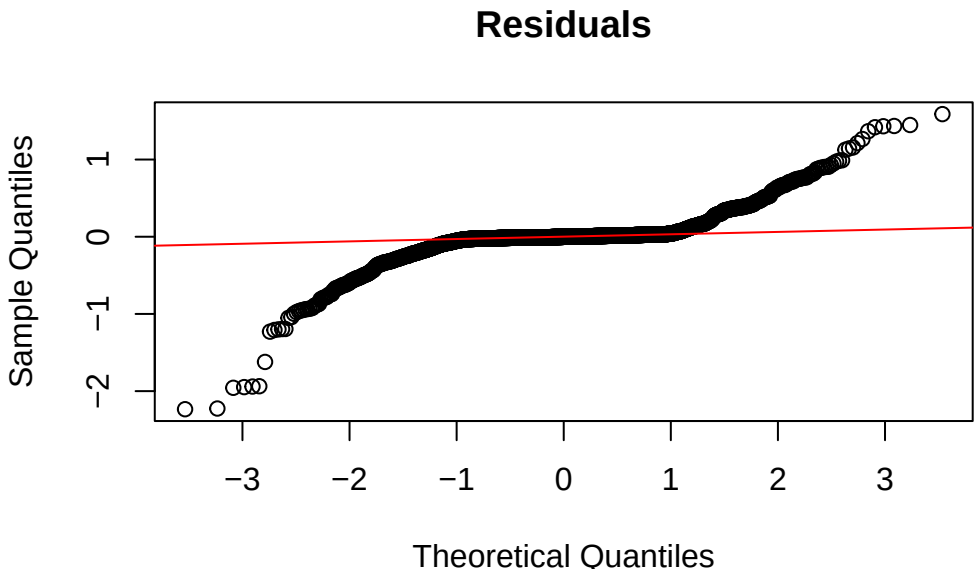
```
                  df       AIC
lmm_model_changed 10  9632.967
gls_model          9 33214.656
```

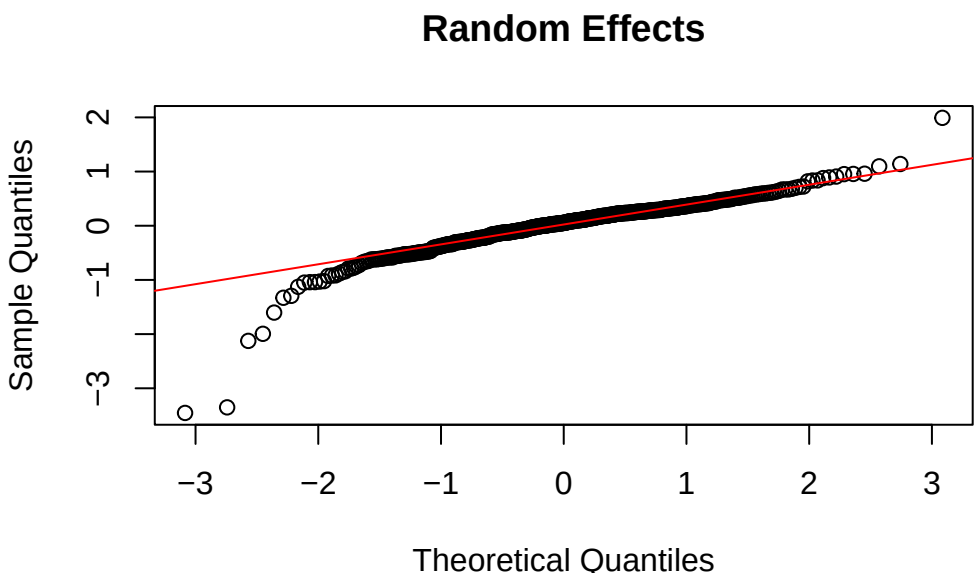
```
                  df      BIC
lmm_model_changed 10  9678.69
gls_model          9 33266.90
```

```
Type III Analysis of Variance Table with Satterthwaite's method
                       Sum Sq Mean Sq NumDF DenDF F value Pr(>F)
Scenario               3177443  794361     4   568 22.8310 <2e-16 ***
region_category         284976  142488     2   139  4.0953 0.0187 *
DISPATCH.PRIORITY.NAME   58272   58272     1   139  1.6748 0.1978
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
                  df       AIC
lmm_model_changed 10  9632.967
gls_model_pow     18 32954.167
```

```
                    df      BIC
lmm_model_changed 10  9678.69
gls_model_pow     18 33058.59
```






```
                Model df      AIC      BIC    logLik   Test  L.Ratio p-value
lmm_no_weights      1 10 2129.540 2187.586 -1054.770
lmm_model_ext       2 12 1170.544 1240.200  -573.272 1 vs 2 962.9957  <.0001
```

4. Assumptions and Shortcomings

Normality of residuals was poorly met Large deviances at tails Non-constant variance across fitted values External factors not taken into consideration Traffic / Rush hours/ Road closures Time of year EMT staffing patterns ETT inputs: based on single best-guess estimates (e.g., from Google), lacking nuance or uncertainty Variance modeling: only accounted for regional differences, while

other factors may also influence variability Emergency vs non-emergency Simplicity in Dispatch Rule Better for analysis Doesn't occur in real life

5. Conclusions

Scenario 3 results in the fastest overall response times Marginal mean travel times (ETTs) are reduced by ~16% compared with the baseline (Scenario 0)

$\exp(-0.173) \quad 0.84 \rightarrow$ travel times in Scenario 3 are about 84% of baseline levels