# Prediction Model for Patients' Length of Stay in Emergency Room

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## I. Research Question

The research interest is to estimate the length of emergency room stay until discharge or hospital admission (*los*) given patients' information when they first arriave at the ED and give the range of plausible estimated values.

## II. Data Transformation

To explore the relationship between 7 predictors and outcome, we draw several plots then decide to do some data transformation and create new variables: *weekday* is a dummy variable indicating whether the patient arrive on weekday; *prenoon* is a dummy variable indicating whether the patient arrive before the noon (*tod*=[12AM-11:59AM]); *acu23* is a dummy variable indicating *acuity* is level "2" or "3"; For the presenting symptoms category, we classify the 163 symptoms into 6 types (*type* variable) according to the average *los* for patients with each symptom (see Supplement). There are 9642 missing values (19% of the data set) in *type* variable, since dropping them will lose many information, we decide use multivariate imputation method to impute the missing *type* variable. There are only 329 (0.65% of the data set) patients with unknown gender, then we just dropped those data.

## III. Model

Since the outcome variable (length of stay) is recorded in minutes, it can be treated as count data. While the data are highly over-dispered (the variance of *los* is 400 times over its mean), we decide to use the negative binomial regression model with log link function.

To determine the full model, we plot the outcome variable *los* against *age* and stratified by other categorical variables, we also plot the outcome variable against different acuity level (*acuity*) and stratified by *weekday*.

**Fig 1**

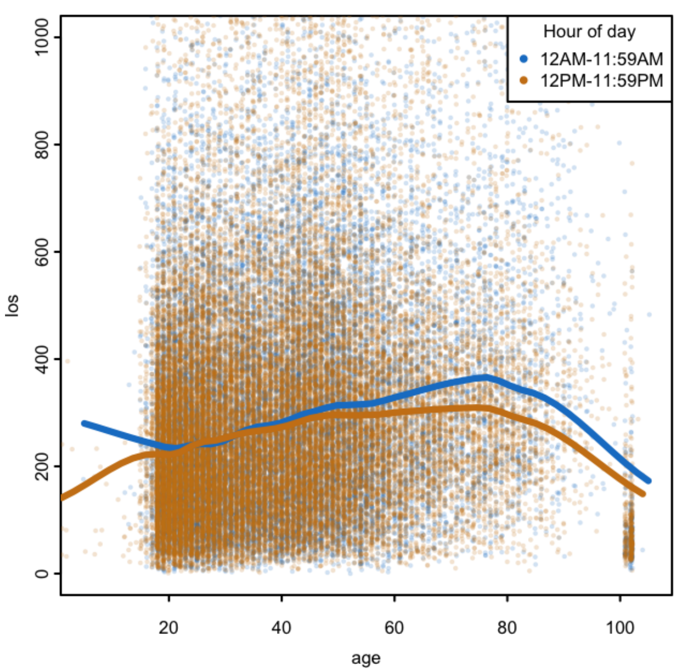



**Fig 2**

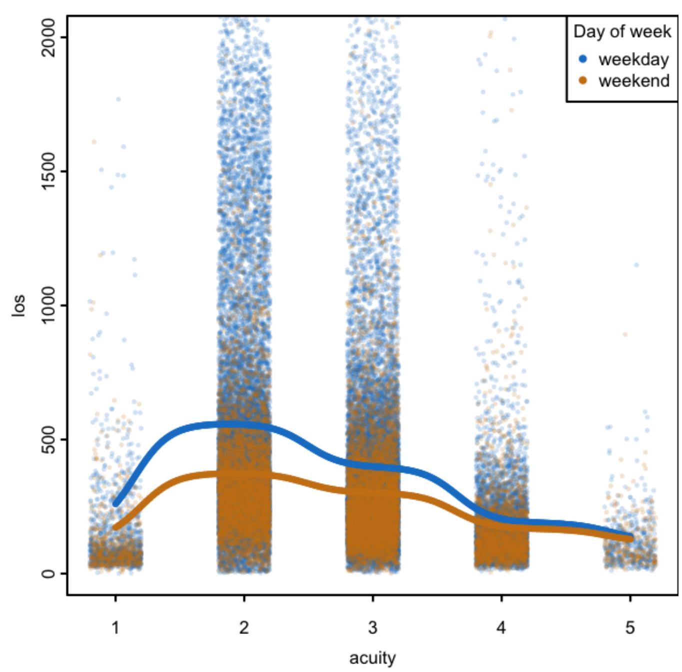



Fig 1 showes that the length of stay has an non-linear relationship with age, therefore we apply linear spline on *age* with knots at 25 and 85. The result of the likelihood ratio test comparing with the model without linear spline

($p = 1.61 \times 10^{-78}$) shows that linear spline significantly improves the model fitting. Fig 1 also shows that patients arrive before noon (blue curve) have longer length of stay, and the difference between *los* before and after noon changes with *age*. Therefore, we include the interaction term of *age* and *prenoon*. In the same way, we include the interaction terms of *age* and *weekday*, *age* and *gender*. Fig 2 shows there is significant relationship between length of stay and acuity level, and it may be modified by *weekday*. Therefore we include the interaction term of acuity level and weekday. Also, we add the indicators of 6 symptoms types (dummy variable of *type*) as the covariates into the model.

Then we fit a full model and performe several likelihood ratio tests to drop non-significant terms and decide the fianl model.

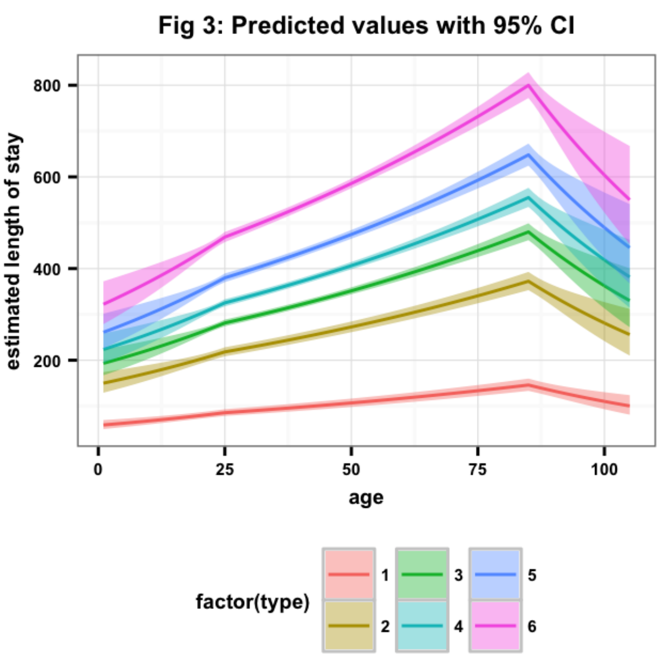
## IV. Assumptions and Model Checking

First, we check for the independence assumption by checking the correlation between two patients' standardized residuals. The correlation plot shows there is no significant correlation between two patients. Then, we check if average standardized residual equals to 0 at each level of predicted values by plotting the average standarized residual in different predicated value intervals, and the result shows the final model is a good fit. We also check for the highly influential points by dropping points using the criteria "dffits>0.17" and 59 points are dropped. Then we refit the same model and compare the coefficients and predicted values before and after dropping. Result shows that there are few highly influential points and the model is robust enough. The result of 10-fold cross-validation shows the model's prediction performance is pretty good and there is no overfitting. Results are shown in Supplement.

## V. Results and Interpretation

By using the final model fitted in III, we could predict the length of stay in the ED and calculate the 95% confidence interval of the predicted values.

Fig 3 shows the predicted length of stay with 95% confidence interval for female patients who arrive on weekday during 12AM-11:59AM with acuity level 2 or 3, and the results are stratified by 6 symptom types indicated by color. Through Fig 3, we could see the predicted length of stay gets longer for patients from type 1 to type 6, when controlled for other predictors. This phenomenon is as expected since those types are generated by the average length of stay. The confidence intervals in Fig 3 show that for patients younger than 25 years old, the variance of predicted values decreases with age, while for patients older than 25 years old the variance will increase with age. And the variance of predicated value for patients in type 1, 2, 3 will be smaller than the variance for patients in type 4, 5, 6. The results for male patients and other arrival time and acuity levels are similar to those conclutions.



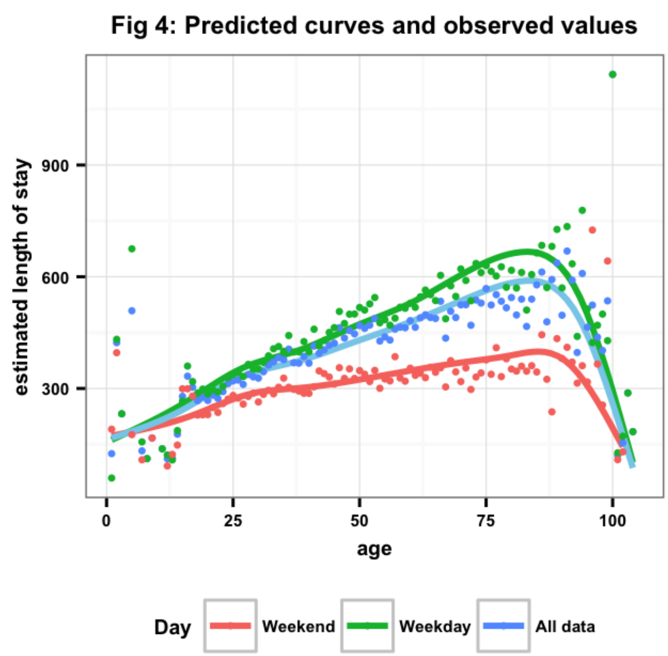




*Fig 3 is for female patients arrive on weekday during 12AM-11:59AM and have acuity level 2 or 3; Fig 4 is for all patients*

Table 1: Predicted values with 95% CI for female patients with acuity level 2 and 3 (symptom type=4)

| **Day** | **Weekday** | | | | **Weekend** | | | |
|---|---|---|---|---|---|---|---|---|
| **Time** | **[12AM-11:59AM]** | | **[12PM-11:59PM]** | | **[12AM-11:59AM]** | | **[12PM-11:59PM]** | |
| Age | $\widehat{los}$ | 95% CI | $\widehat{los}$ | 95% CI | $\widehat{los}$ | 95% CI | $\widehat{los}$ | 95% CI |
| 10 | 257.19 | (235.55 , 280.83) | 220.99 | (206.76 , 236.20) | 218.31 | (199.88 , 238.43) | 173.44 | (162.05 , 185.64) |
| 20 | 300.72 | (291.72 , 309.99) | 304.58 | (297.40 , 311.94) | 255.25 | (246.66 , 264.14) | 239.05 | (232.32 , 245.97) |
| 30 | 339.98 | (332.69 , 347.42) | 372.71 | (365.91 , 379.64) | 280.49 | (272.82 , 288.39) | 284.33 | (277.68 , 291.14) |
| 40 | 371.65 | (364.63 , 378.81) | 404.92 | (398.26 , 411.70) | 289.70 | (282.62 , 296.95) | 291.85 | (285.77 , 298.05) |
| 50 | 406.28 | (398.43 , 414.29) | 439.92 | (432.44 , 447.53) | 299.20 | (291.71 , 306.90) | 299.56 | (293.11 , 306.16) |
| 60 | 444.14 | (434.12 , 454.39) | 477.94 | (468.53 , 487.55) | 309.02 | (300.05 , 318.26) | 307.48 | (299.70 , 315.47) |
| 70 | 485.52 | (472.13 , 499.30) | 519.25 | (506.89 , 531.92) | 319.17 | (307.94 , 330.80) | 315.61 | (305.83 , 325.71) |
| 80 | 530.76 | (512.94 , 549.21) | 564.13 | (547.94 , 580.80) | 329.64 | (315.62 , 344.28) | 323.96 | (311.74 , 336.66) |
| 90 | 505.34 | (477.57 , 534.72) | 533.79 | (506.27 , 562.81) | 320.11 | (299.52 , 342.12) | 312.65 | (293.61 , 332.92) |
| 100 | 419.04 | (362.32 , 484.63) | 439.90 | (380.85 , 508.10) | 292.28 | (246.86 , 346.06) | 283.71 | (239.92 , 335.49) |

Table 2: Predicted values with 95% CI for female patients with acuity level 1,4 and 5 (symptom type=4)

| **Day** | **Weekday** | | | | **Weekend** | | | |
|---|---|---|---|---|---|---|---|---|
| **Time** | **[12AM-11:59AM]** | | **[12PM-11:59PM]** | | **[12AM-11:59AM]** | | **[12PM-11:59PM]** | |
| Age | $\widehat{los}$ | 95% CI | $\widehat{los}$ | 95% CI | $\widehat{los}$ | 95% CI | $\widehat{los}$ | 95% CI |
| 10 | 160.89 | (142.67 , 181.44) | 138.25 | (125.28 , 152.55) | 156.28 | (138.48 , 176.37) | 124.17 | (112.33 , 137.25) |
| 20 | 166.57 | (160.00 , 173.40) | 168.71 | (163.10 , 174.51) | 161.80 | (154.68 , 169.24) | 151.53 | (145.69 , 157.60) |
| 30 | 175.80 | (170.49 , 181.27) | 192.73 | (187.33 , 198.27) | 165.98 | (159.80 , 172.41) | 168.25 | (162.50 , 174.21) |
| 40 | 189.15 | (184.19 , 194.25) | 206.09 | (201.01 , 211.29) | 168.73 | (162.98 , 174.69) | 169.98 | (164.64 , 175.50) |
| 50 | 203.52 | (197.60 , 209.63) | 220.38 | (214.25 , 226.68) | 171.53 | (165.17 , 178.12) | 171.73 | (165.78 , 177.90) |
| 60 | 218.99 | (210.83 , 227.46) | 235.65 | (227.22 , 244.40) | 174.37 | (166.55 , 182.55) | 173.50 | (166.12 , 181.20) |
| 70 | 235.62 | (224.34 , 247.47) | 251.99 | (240.40 , 264.14) | 177.25 | (167.45 , 187.64) | 175.28 | (166.03 , 185.05) |
| 80 | 253.52 | (238.42 , 269.59) | 269.46 | (254.06 , 285.80) | 180.19 | (168.09 , 193.17) | 177.09 | (165.70 , 189.25) |
| 90 | 211.03 | (196.20 , 226.98) | 222.91 | (207.96 , 238.94) | 152.98 | (141.12 , 165.84) | 149.42 | (138.34 , 161.38) |
| 100 | 135.89 | (116.10 , 159.05) | 142.65 | (122.16 , 166.58) | 108.47 | (91.24 , 128.96) | 105.29 | (88.76 , 124.89) |

In Fig 4, the points are the observed average length of stay for each age and the lines are smooth curves of predicted values, and color indicates whether patients arrive on weekday or weekend. This figure shows the final model is a good fit for the data and *weekday* is an important predictor in predicting the lenght of stay: Patients arrive on weekday will have longer predicted length of stay compared with patients in same condition but arrive on weekend.

Fig 3 and Fig 4 both show the relationship between age and predicted length of stay. For people in age group 0-85 years old, older patients have longer predicted length of stay when keep other predictors as the same; For people in age group 85-105 years old, older patients will have shorter predicted values when keep other predictors as the same.

To specify, we display the prediction results for female patients in a specific type group (type 4) shown by the two tables above. Table 1 and Table 2 summary the predicted values with 95% confidence interval by age, acuity level, arrival day and time.

Through Table 1 and Table 2 above, we could conclude that, female patients with acuity level 2 or 3 will have longer predicted length of stay in all age groups compared with other acuity levels regardless of arrival time. And if female patients arrive on weekday they will have longer predicted length of stay regardless other predictors. The relationship between predicted length of stay and arrival time varies with age. And the 95% confidence intervals are narrow enough so that the variance of predicted values are plausible.

In conclusion, when controlled for other predictors, the predicted length of stay gets longer with increase of age when people are younger than 85 years old, while it will get shorter with increase of age when people are older than 85. Patients in same condition will have longer predicted length of stay if they arrive on weekday, with acuity level 2 or 3, or have high level symptom type (type 6, 5, 4). The relationship between age and predicted length of stay is also modified by acuity level, gender, arrival day and time.

# Supplement

## I. Symptom Types

Symptom types category is shown in Table 3 below.

## II. Assumptions Checking

### 1. Independence assumption

Fig S1: correlation betwen two patients

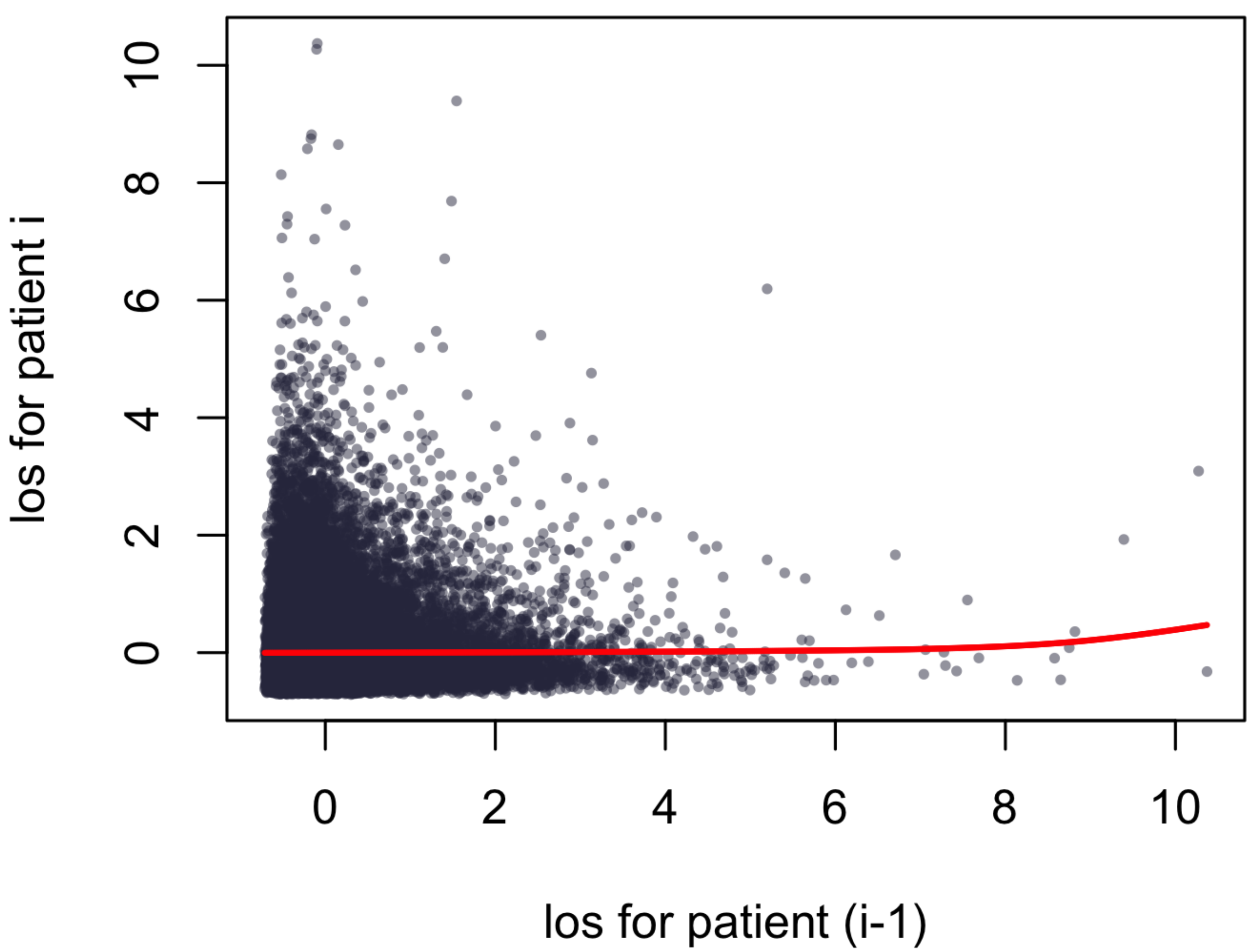
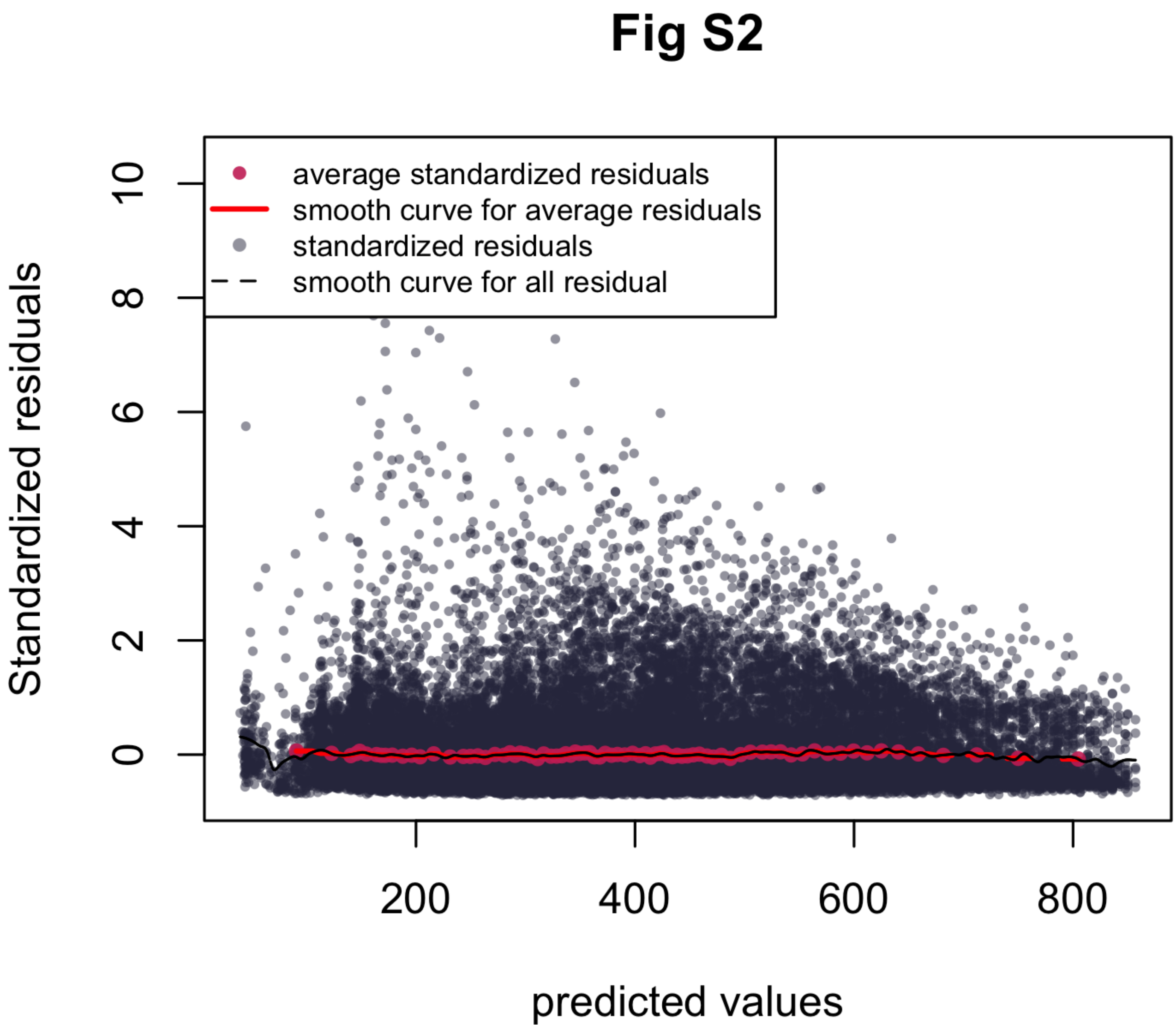


Table 3: Symptom Types

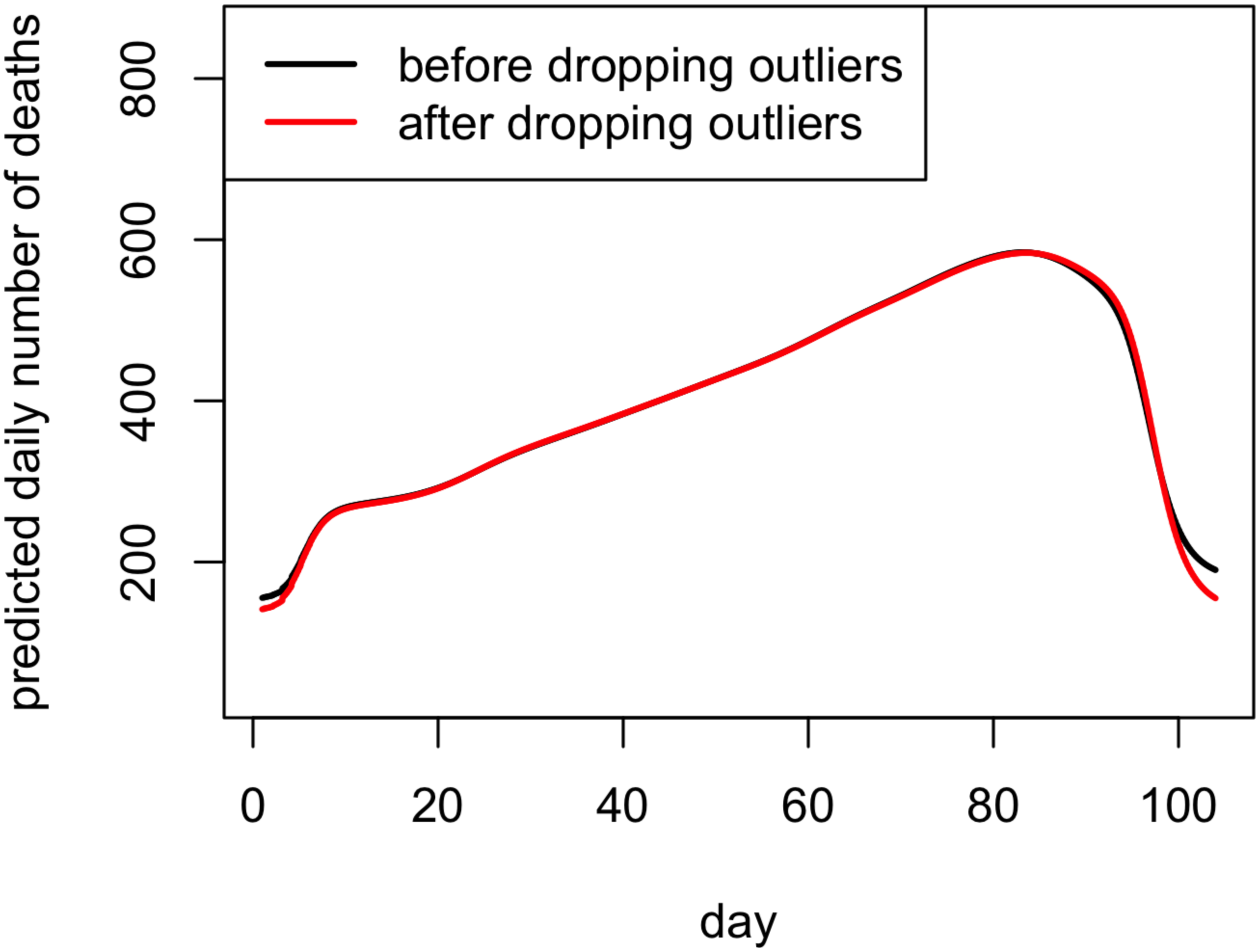
| key | meanlos | type | key | meanlos | type | key | meanlos | type |
|---|---|---|---|---|---|---|---|---|
| aaa | 58 | 1 | suture | 69 | 1 | cough | 378 | 4 |
| abd | 83 | 1 | sz | 70 | 1 | depress | 354 | 4 |
| abscess | 13 | 1 | test | 22 | 1 | flank | 393 | 4 |
| all over | 28 | 1 | thigh | 38 | 1 | flu | 370 | 4 |
| aneurysm | 68 | 1 | to or | 49 | 1 | groin | 342 | 4 |
| asthma | 14 | 1 | toe | 32 | 1 | gu | 399 | 4 |
| bleeding | 5 | 1 | tooth | 42 | 1 | ha | 301 | 4 |
| bp | 67 | 1 | unknown | 35 | 1 | head | 300 | 4 |
| c-sec comp | 11 | 1 | a&d | 117 | 2 | headache | 385 | 4 |
| check | 12 | 1 | bness | 134 | 2 | hematuria | 369 | 4 |
| clot | 60 | 1 | cancer | 118 | 2 | hip | 347 | 4 |
| confusion | 75 | 1 | cardiac | 144 | 2 | jaundice | 303 | 4 |
| cramp | 10 | 1 | cath | 115 | 2 | palp | 348 | 4 |
| dehydr | 40 | 1 | congestion | 189 | 2 | phylaxis | 304 | 4 |
| deliver | 21 | 1 | cp | 135 | 2 | preg | 351 | 4 |
| detox | 86 | 1 | cva | 169 | 2 | problem | 326 | 4 |
| disorie | 43 | 1 | dynia | 159 | 2 | rib | 315 | 4 |
| etoh | 38 | 1 | ear | 133 | 2 | scan | 313 | 4 |
| eval | 100 | 1 | hand | 193 | 2 | skin | 330 | 4 |
| faint | 45 | 1 | lab | 178 | 2 | abnormal | 467 | 5 |
| finger | 87 | 1 | op comp | 105 | 2 | ad | 435 | 5 |
| flash | 47 | 1 | psych | 127 | 2 | complication | 430 | 5 |
| follow | 24 | 1 | refill | 108 | 2 | diz | 411 | 5 |
| foot | 73 | 1 | s/p | 185 | 2 | general | 488 | 5 |
| gen ill | 58 | 1 | sah | 116 | 2 | hemoptysis | 497 | 5 |
| heart | 78 | 1 | snake | 178 | 2 | hypoglycemia | 490 | 5 |
| infect | 5 | 1 | wrist | 174 | 2 | kidney | 417 | 5 |
| liver | 12 | 1 | anxi | 278 | 3 | muscle | 437 | 5 |
| med | 16 | 1 | arm | 279 | 3 | pe | 479 | 5 |
| migra | 9 | 1 | back | 295 | 3 | seizure | 408 | 5 |
| mouth | 81 | 1 | dtoh | 207 | 3 | si | 465 | 5 |
| nausea | 40 | 1 | dysuria | 290 | 3 | site | 458 | 5 |
| needs | 73 | 1 | elbow | 229 | 3 | stool | 466 | 5 |
| nose | 76 | 1 | epistaxis | 289 | 3 | tachycardia | 492 | 5 |
| passed out | 9 | 1 | eye | 226 | 3 | vertigo | 465 | 5 |
| picu | 56 | 1 | feet | 201 | 3 | wheezing | 491 | 5 |
| poison | 60 | 1 | insom | 279 | 3 | ams | 591 | 6 |
| pressure | 75 | 1 | knee | 234 | 3 | breath | 553 | 6 |
| rabies | 70 | 1 | leg | 297 | 3 | chestpain | 527 | 6 |
| rectal | 14 | 1 | lle | 245 | 3 | chill | 557 | 6 |
| removal | 33 | 1 | n/v | 247 | 3 | clearance | 566 | 6 |
| respira | 78 | 1 | neck | 263 | 3 | constipation | 510 | 6 |
| results | 6 | 1 | obs | 210 | 3 | diarr | 509 | 6 |
| rx | 42 | 1 | pain | 283 | 3 | dyspnea | 524 | 6 |
| sa | 87 | 1 | rash | 200 | 3 | extremity | 501 | 6 |
| scc | 44 | 1 | shoulder | 229 | 3 | fever | 646 | 6 |
| shiver | 81 | 1 | sore | 205 | 3 | gi | 505 | 6 |
| shot | 22 | 1 | throat | 273 | 3 | hyperglycemia | 510 | 6 |
| sinu | 35 | 1 | transfer | 233 | 3 | ingestion | 541 | 6 |
| sob | 90 | 1 | urticaria | 229 | 3 | lung | 600 | 6 |
| std | 24 | 1 | voice | 239 | 3 | melena | 613 | 6 |
| stitch | 76 | 1 | | | | mi | 530 | 6 |
| stoma | 42 | 1 | | | | null | 1133 | 6 |
| sugar | 76 | 1 | | | | stridor | 531 | 6 |
| surg | 68 | 1 | | | | thrive | 1022 | 6 |
| | | | | | | weak | 578 | 6 |
| | | | | | | weight | 584 | 6 |

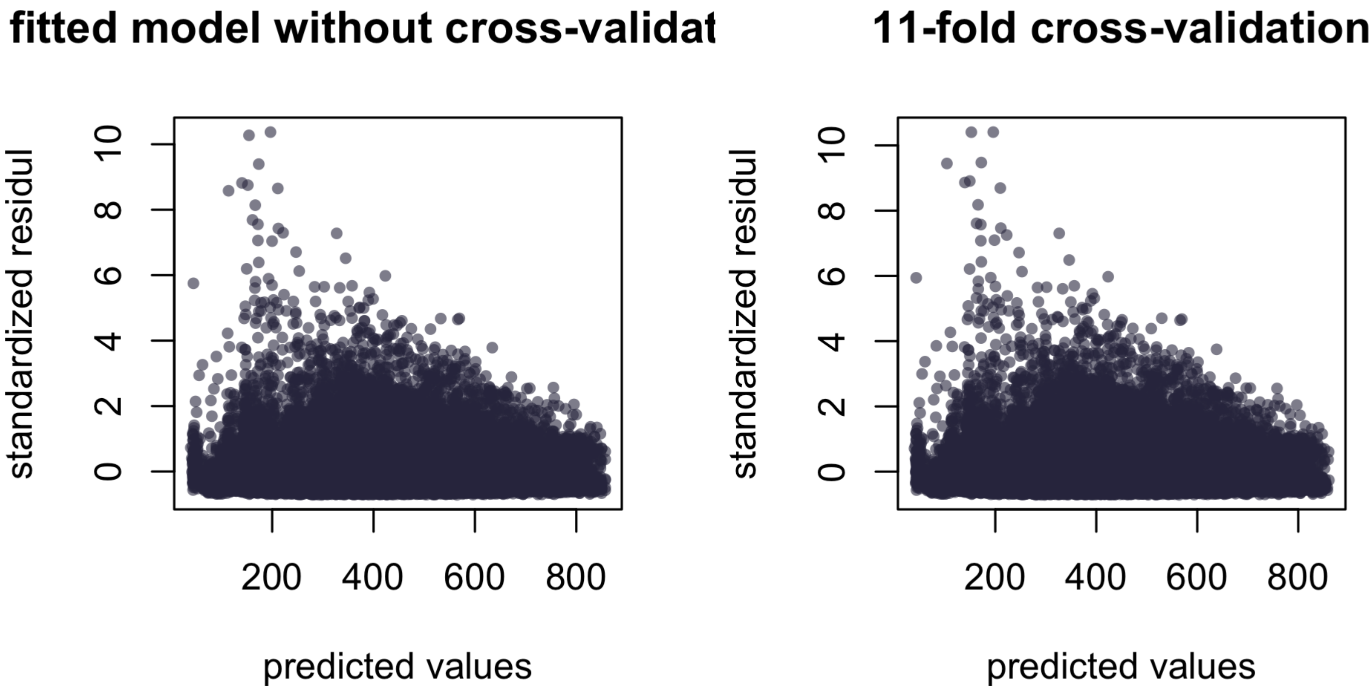
**2. Average Standardized residual**



**3. Highly influency points**

Fig S4: smooth curve of predicated values




fitted model without cross-validat
11-fold cross-validation
standardized residul
0
2
4
6
8
10
200
400
600
800
predicted values