STA 325 Final Project Code

Calleigh Smith, Hannah Bogomilsky, Hugh Esterson, Maria Henriquez, Mariana Izon

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```
library(readr)
library(dplyr)
library(tidyverse)
library(gridExtra)
library(mgcv)
library(patchwork)
library(MASS)
library(EnvStats)
library(tree)
library(randomForest)
library(gbm)
library(bst)
library(plyr)
library(caret)
```

Data Load-In and Initial Cleaning

```
# read data
flights <- read_csv("data/flights.csv")

# find unique airlines, destinations, and types of delays
unique(flights$OP_CARRIER)
```

```
## [1] "AA" "DL" "B6" "AS"
```

```
unique(flights$DEST)
```

```
##  [1] "LAX" "SFO" "SJC" "SAN" "PSP" "SMF" "OAK" "LGB" "ONT" "BUR"
```

```
# mutate delays and filter out NA arrival delays
flights <- flights %>%
  mutate(CARRIER_DELAY = case_when(CARRIER_DELAY > 0 ~ 1,
                                   TRUE ~ 0),
         WEATHER_DELAY = case_when(WEATHER_DELAY > 0 ~ 1,
            TRUE ~ 0),
         NAS_DELAY = case_when(NAS_DELAY > 0 ~ 1,
                               TRUE ~ 0),
         SECURITY_DELAY = case_when(SECURITY_DELAY > 0 ~ 1,
                                    TRUE ~ 0),
         LATE_AIRCRAFT_DELAY = case_when(LATE_AIRCRAFT_DELAY > 0 ~ 1,
                                         TRUE ~ 0)) %>%
  filter(!is.na(ARR_DELAY))
```

```r
# glimpse data
flights
```

```
## # A tibble: 2,033 x 34
##     YEAR MONTH DAY_OF_MONTH DAY_OF_WEEK FL_DATE    OP_CARRIER TAIL_NUM
##    <dbl> <dbl>        <dbl>       <dbl> <date>     <chr>      <chr>
##  1  2020     1            1           3 2020-01-01 AA         N110AN
##  2  2020     1            2           4 2020-01-02 AA         N111ZM
##  3  2020     1            3           5 2020-01-03 AA         N108NN
##  4  2020     1            4           6 2020-01-04 AA         N102NN
##  5  2020     1            5           7 2020-01-05 AA         N113AN
##  6  2020     1            6           1 2020-01-06 AA         N103NN
##  7  2020     1            7           2 2020-01-07 AA         N113AN
##  8  2020     1            8           3 2020-01-08 AA         N106NN
##  9  2020     1            9           4 2020-01-09 AA         N102NN
## 10  2020     1           10           5 2020-01-10 AA         N117AN
## # ... with 2,023 more rows, and 27 more variables: OP_CARRIER_FL_NUM <dbl>,
## #   ORIGIN <chr>, ORIGIN_CITY_NAME <chr>, DEST <chr>, DEST_CITY_NAME <chr>,
## #   CRS_DEP_TIME <dbl>, DEP_TIME <dbl>, DEP_DELAY <dbl>, TAXI_OUT <dbl>,
## #   WHEELS_OFF <dbl>, WHEELS_ON <dbl>, TAXI_IN <dbl>, CRS_ARR_TIME <dbl>,
## #   ARR_TIME <dbl>, ARR_DELAY <dbl>, CANCELLED <dbl>, CANCELLATION_CODE <lgl>,
## #   DIVERTED <dbl>, CRS_ELAPSED_TIME <dbl>, ACTUAL_ELAPSED_TIME <dbl>,
## #   AIR_TIME <dbl>, DISTANCE <dbl>, CARRIER_DELAY <dbl>, WEATHER_DELAY <dbl>,
## #   NAS_DELAY <dbl>, SECURITY_DELAY <dbl>, LATE_AIRCRAFT_DELAY <dbl>
```

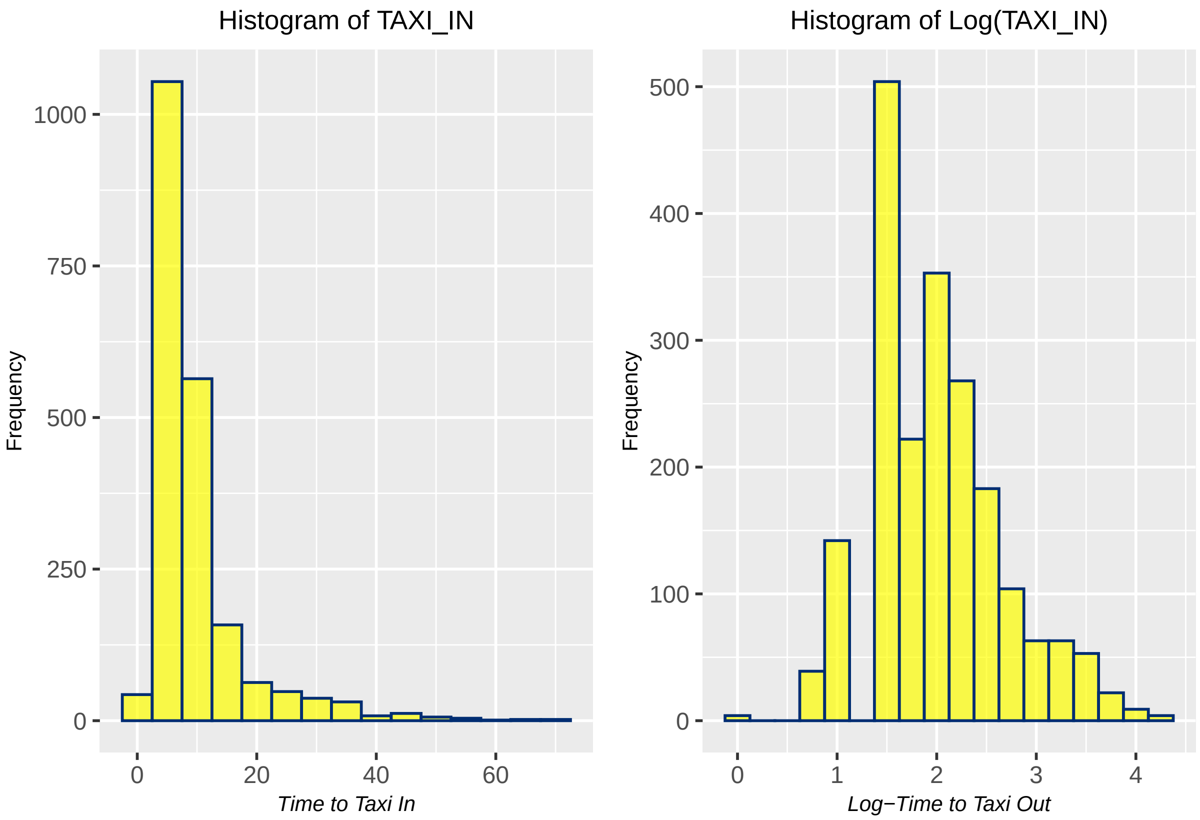
Exploratory Data Analysis

Individual Predictor Variable EDA

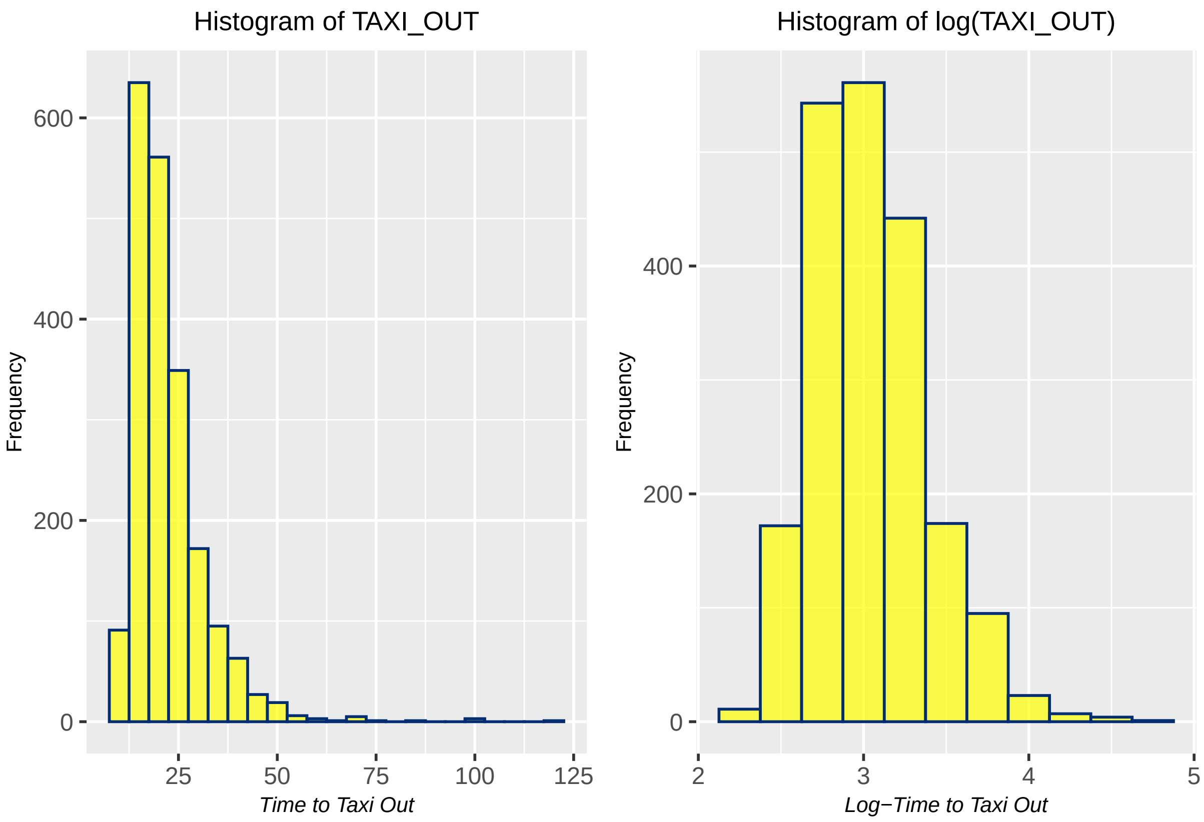
Taxi Histograms

```r
# plot untransformed predictor taxi_in
pTAXI_IN <- ggplot(data = flights, aes(x = TAXI_IN)) +
  geom_histogram(binwidth = 5, fill = "#FFFF00", color = "#002D72", alpha = .7) +
  labs(x = "Time to Taxi In",
       y = "Frequency",
       title = "Histogram of TAXI_IN") +
  theme(plot.title = element_text(size = 10,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# plot untransformed predictor taxi_out
pTAXI_OUT <- ggplot(data = flights, aes(x = TAXI_OUT)) +
  geom_histogram(binwidth = 5, fill = "#FFFF00", color = "#002D72", alpha = .7) +
  labs(x = "Time to Taxi Out",
       y = "Frequency",
       title = "Histogram of TAXI_OUT") +
  theme(plot.title = element_text(size = 10,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# log transform taxi_in and taxi_out
flights$log_TAXI_OUT <- log(flights$TAXI_OUT)
flights$log_TAXI_IN <- log(flights$TAXI_IN)

# plot log transformed taxi_out
plog_TAXI_OUT <- ggplot(data = flights, aes(x = log_TAXI_OUT)) +
  geom_histogram(binwidth = .25, fill = "#FFFF00", color = "#002D72", alpha = .7) +
  labs(x = "Log-Time to Taxi Out",
       y = "Frequency",
       title = "Histogram of log(TAXI_OUT)") +
  theme(plot.title = element_text(size = 10,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# plot log transform taxi_in
plog_TAXI_IN <- ggplot(data = flights, aes(x = log_TAXI_IN)) +
  geom_histogram(binwidth = .25, fill = "#FFFF00", color = "#002D72", alpha = .7) +
  labs(x = "Log-Time to Taxi Out",
       y = "Frequency",
       title = "Histogram of Log(TAXI_IN)") +
  theme(plot.title = element_text(size = 10,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))
```

```r
pTAXI_IN + plog_TAXI_IN
```

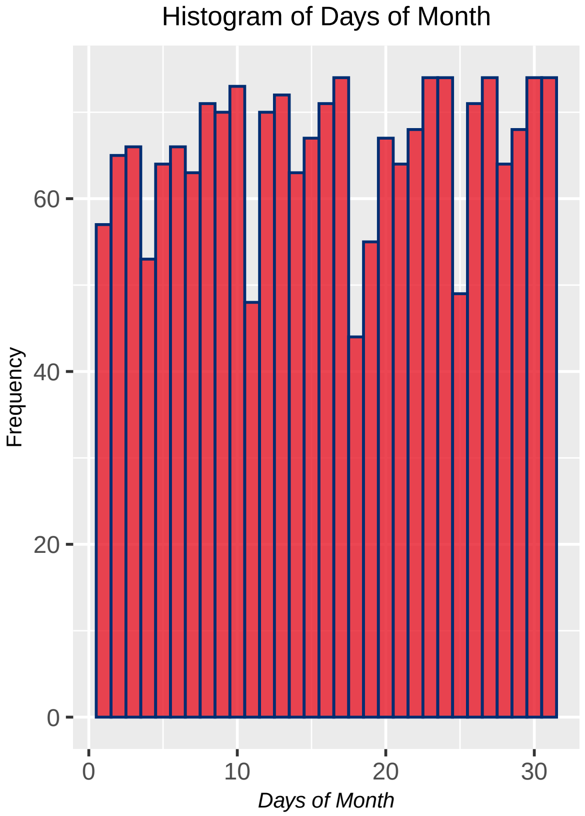


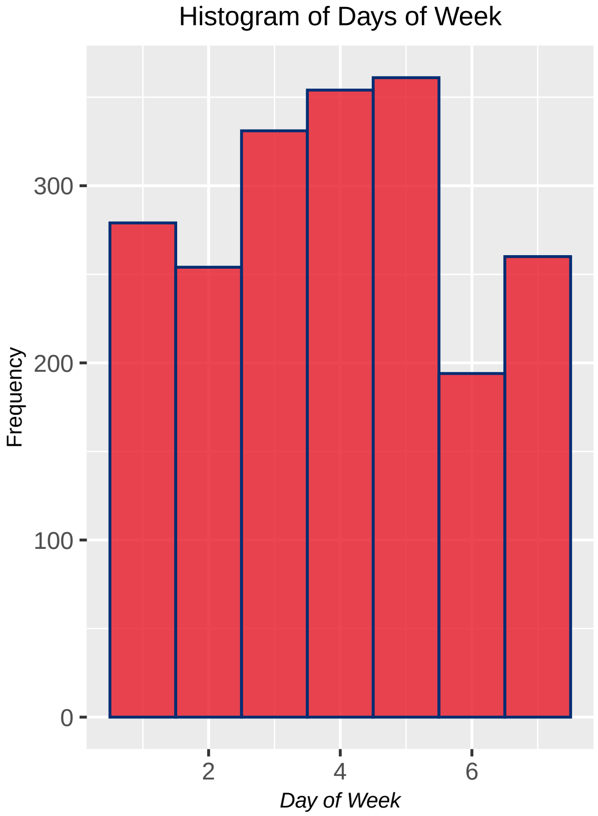
```r
pTAXI_OUT + plog_TAXI_OUT
```



Days of Month and Week

```
# plot predictor DAYS_OF_MONTH
pDOM <- ggplot(data = flights, aes(x = DAY_OF_MONTH)) +
  geom_histogram(binwidth = 1, fill = "#E81828", color = "#002D72", alpha = .8) +
  labs(x = "Days of Month",
       y = "Frequency",
       title = "Histogram of Days of Month") +
    theme(plot.title = element_text(size = 10,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# plot predictor DAY_OF_WEEK
pDOW <- ggplot(data = flights, aes(x = DAY_OF_WEEK)) +
  geom_histogram(binwidth = 1, fill = "#E81828", color = "#002D72", alpha = .8) +
  labs(x = "Day of Week",
       y = "Frequency",
       title = "Histogram of Days of Week") +
    theme(plot.title = element_text(size = 10,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

pDOM + pDOW
```

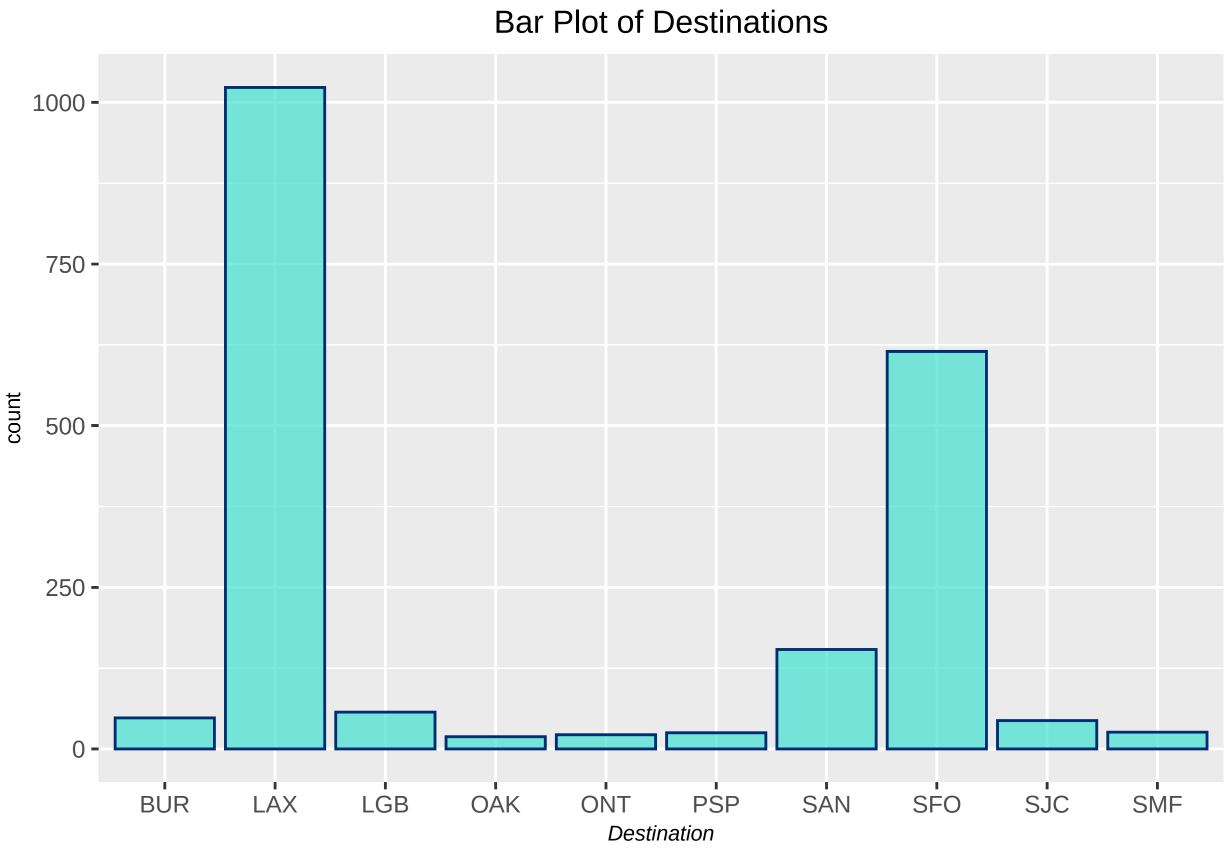




Destination Locations

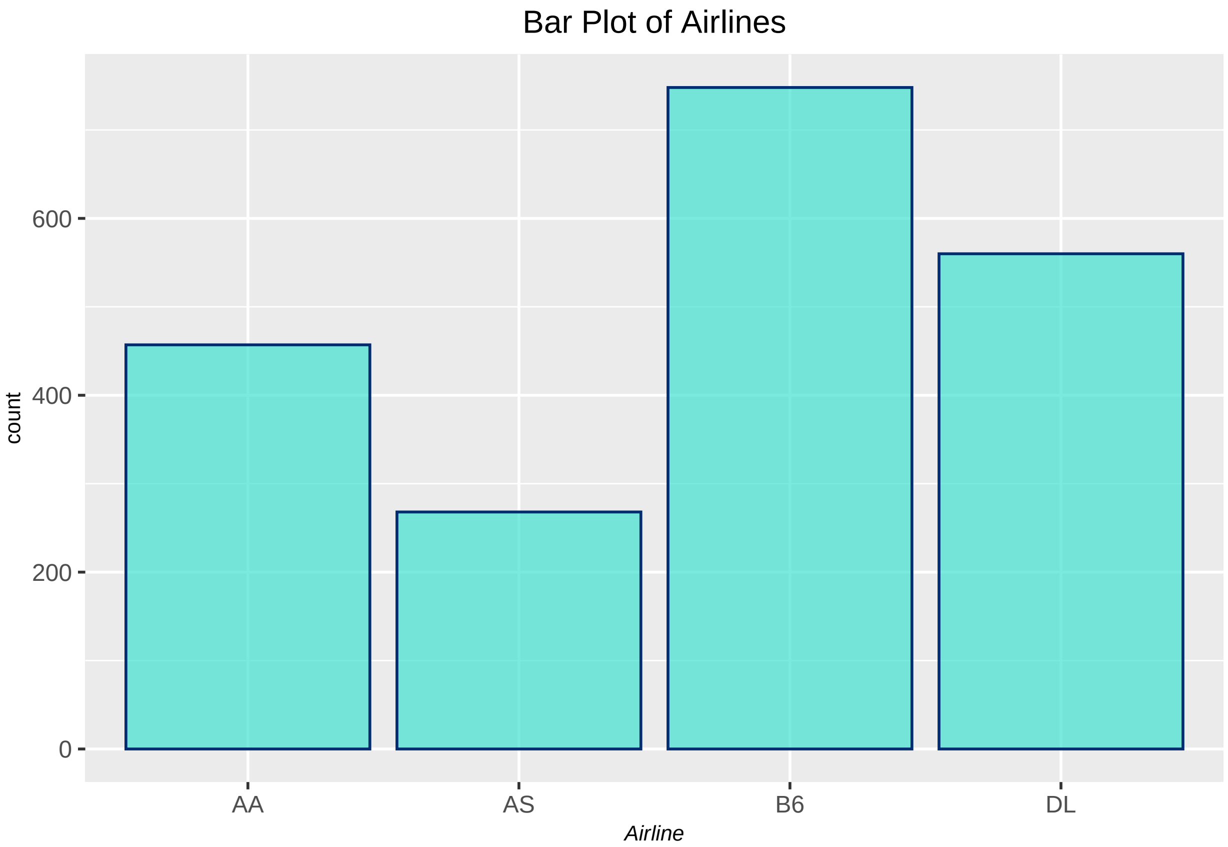
Origin is all JFK, but we could consider the different destination locations.

```r
# plot destinations in CA
pDEST <- ggplot(data = flights, aes(x = DEST)) +
  geom_bar(fill = "#40E0D0", color = "#002D72", alpha = .7) +
  labs(x = "Destination",
       title = "Bar Plot of Destinations") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

pDEST
```



Airlines

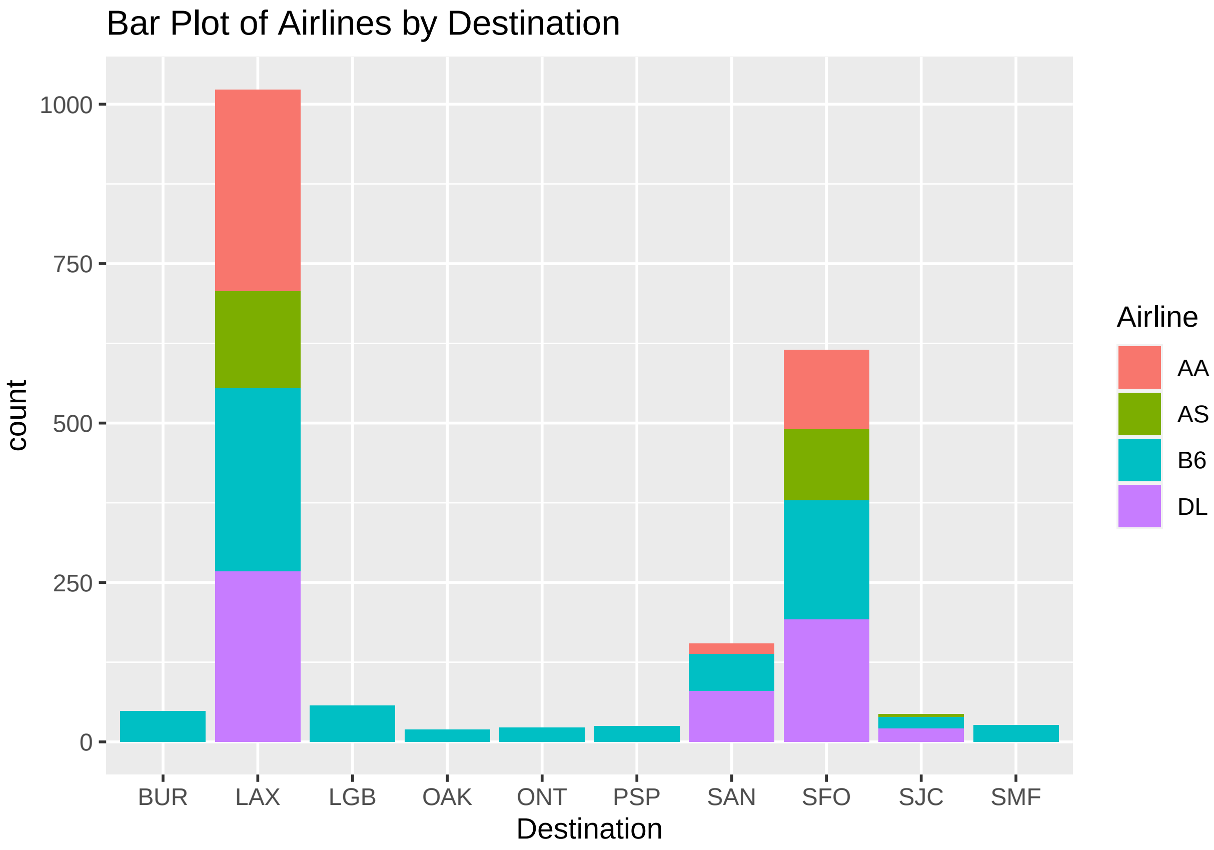
```
# plot airline carriers
pLINE <- ggplot(data = flights, aes(x = OP_CARRIER)) +
  geom_bar(fill = "#40E0D0", color = "#002D72", alpha = .7) +
  labs(x = "Airline",
       title = "Bar Plot of Airlines") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

pLINE
```



```
# plot airlines by destination
pLINEDEST <- ggplot(data = flights, aes(x = DEST, fill = OP_CARRIER)) +
  geom_bar() +
  labs(x = "Destination",
       title = "Bar Plot of Airlines by Destination",
       fill = "Airline")
    theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))
```

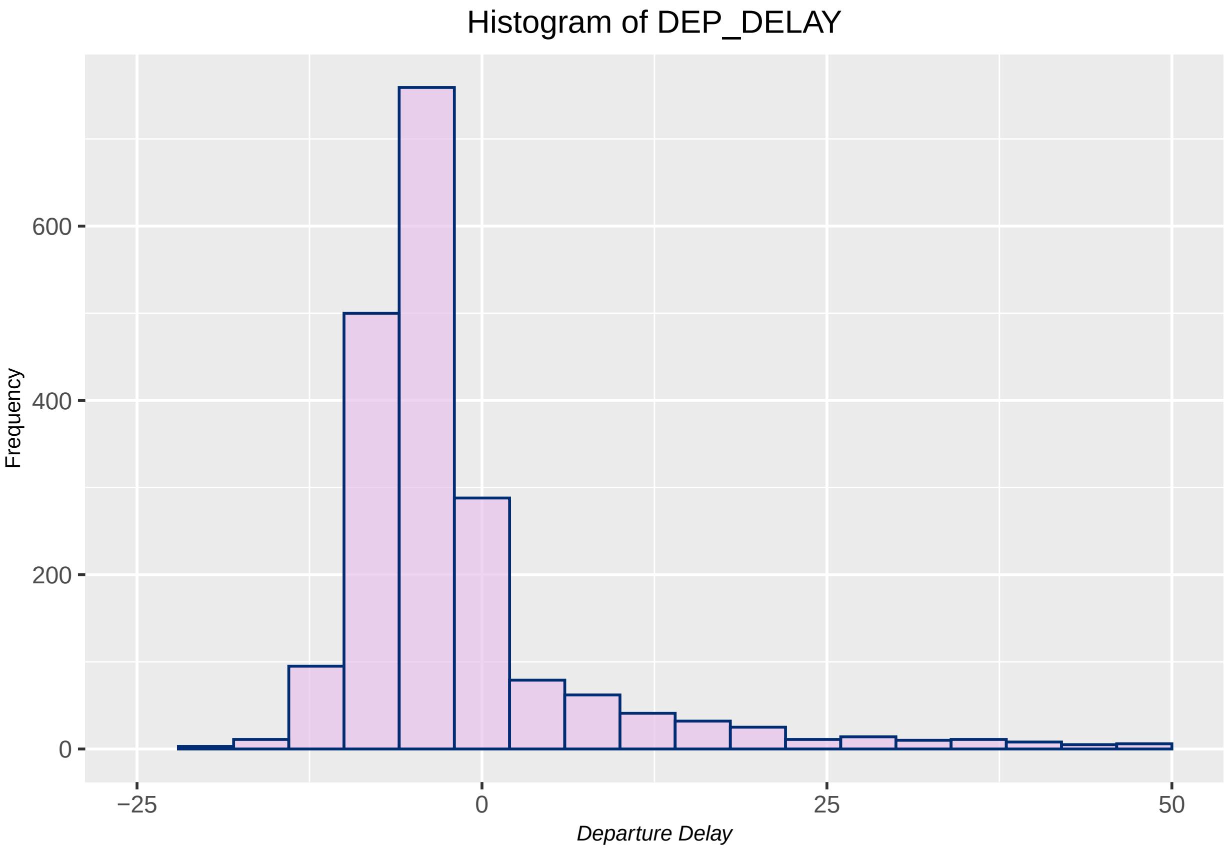
```
## List of 4
##  $ axis.title.x.bottom:List of 11
##   ..$ family       : NULL
##   ..$ face         : chr "italic"
##   ..$ colour       : NULL
##   ..$ size         : num 8
##   ..$ hjust        : NULL
##   ..$ vjust        : NULL
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : NULL
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi FALSE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ axis.title.y.left  :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : num 8
##   ..$ hjust        : NULL
##   ..$ vjust        : NULL
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : NULL
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi FALSE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ plot.title         :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : num 12
##   ..$ hjust        : num 0.5
##   ..$ vjust        : NULL
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : NULL
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi FALSE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  $ plot.subtitle      :List of 11
##   ..$ family       : NULL
##   ..$ face         : NULL
##   ..$ colour       : NULL
##   ..$ size         : NULL
##   ..$ hjust        : num 0.5
##   ..$ vjust        : NULL
##   ..$ angle        : NULL
##   ..$ lineheight   : NULL
##   ..$ margin       : NULL
##   ..$ debug        : NULL
##   ..$ inherit.blank: logi FALSE
##   ..- attr(*, "class")= chr [1:2] "element_text" "element"
##  - attr(*, "class")= chr [1:2] "theme" "gg"
##  - attr(*, "complete")= logi FALSE
##  - attr(*, "validate")= logi TRUE
```

```
pLINEDEST
```

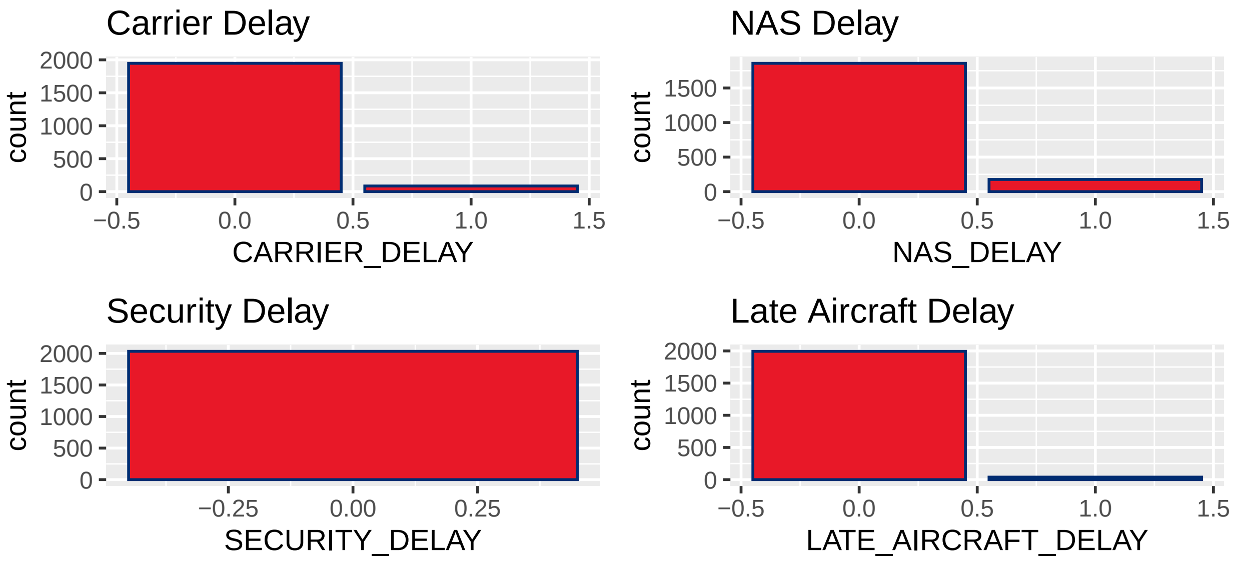


Depart Delay Histogram

```
# plot DEP_DELAY
pDEPDELAY <- ggplot(data = flights, aes(x = DEP_DELAY)) +
  geom_histogram(binwidth = 4, fill = "#e9c2ed", color = "#002D72", alpha = 0.7) +
  xlim(-25, 50) +
  labs(x = "Departure Delay",
       y = "Frequency",
       title = "Histogram of DEP_DELAY") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

pDEPDELAY
```



```
# plot types of delays
p1 <- ggplot(data = flights, aes(x = CARRIER_DELAY)) +
  geom_bar(fill = "#E81828", color = "#002D72") +
  labs(title = "Carrier Delay")

#p2 <- ggplot(data = flights, aes(x = WEATHER_DELAY)) +
  #geom_bar(fill = "#E81828", color = "#002D72") +
  #labs(title = "Weather Delay")

p3 <- ggplot(data = flights, aes(x = NAS_DELAY)) +
  geom_bar(fill = "#E81828", color = "#002D72") +
  labs(title = "NAS Delay")

p4 <- ggplot(data = flights, aes(x = SECURITY_DELAY)) +
  geom_bar(fill = "#E81828", color = "#002D72") +
  labs(title = "Security Delay")

p5 <- ggplot(data = flights, aes(x = LATE_AIRCRAFT_DELAY)) +
  geom_bar(fill = "#E81828", color = "#002D72") +
  labs(title = "Late Aircraft Delay")

grid.arrange(p1,p3,p4,p5, nrow = 3)
```



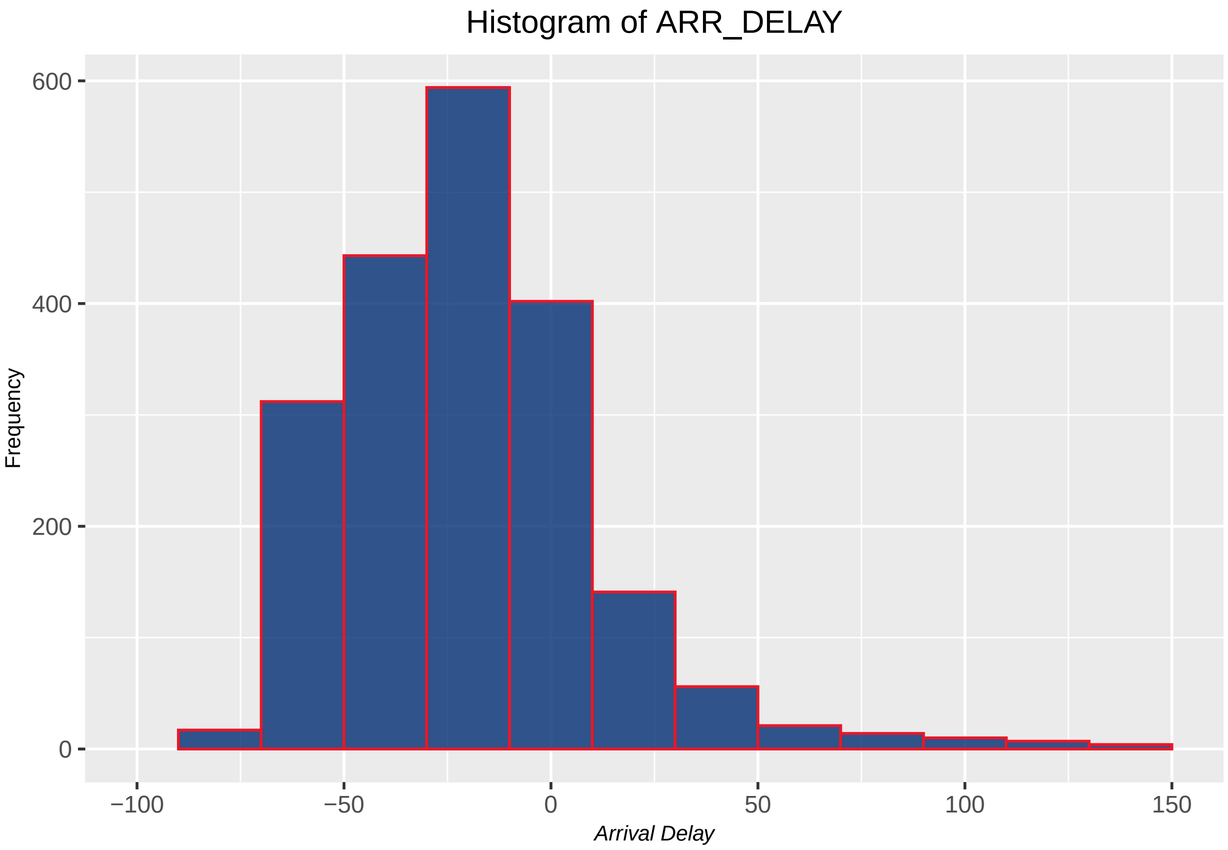
From this EDA of the categorical variables, we probably should not perform analysis with `SECURITY_DELAY` since all of them are classified as 0.

Furthermore, only 9 flights are classified with a weather delay, so it may not be good for our model to include this as a variable for right now.

Overall, the categorical delay predictors I would think we could use are: Carrier Delay, NAS Delay, and Late Aircraft Delay

Response Variable EDA

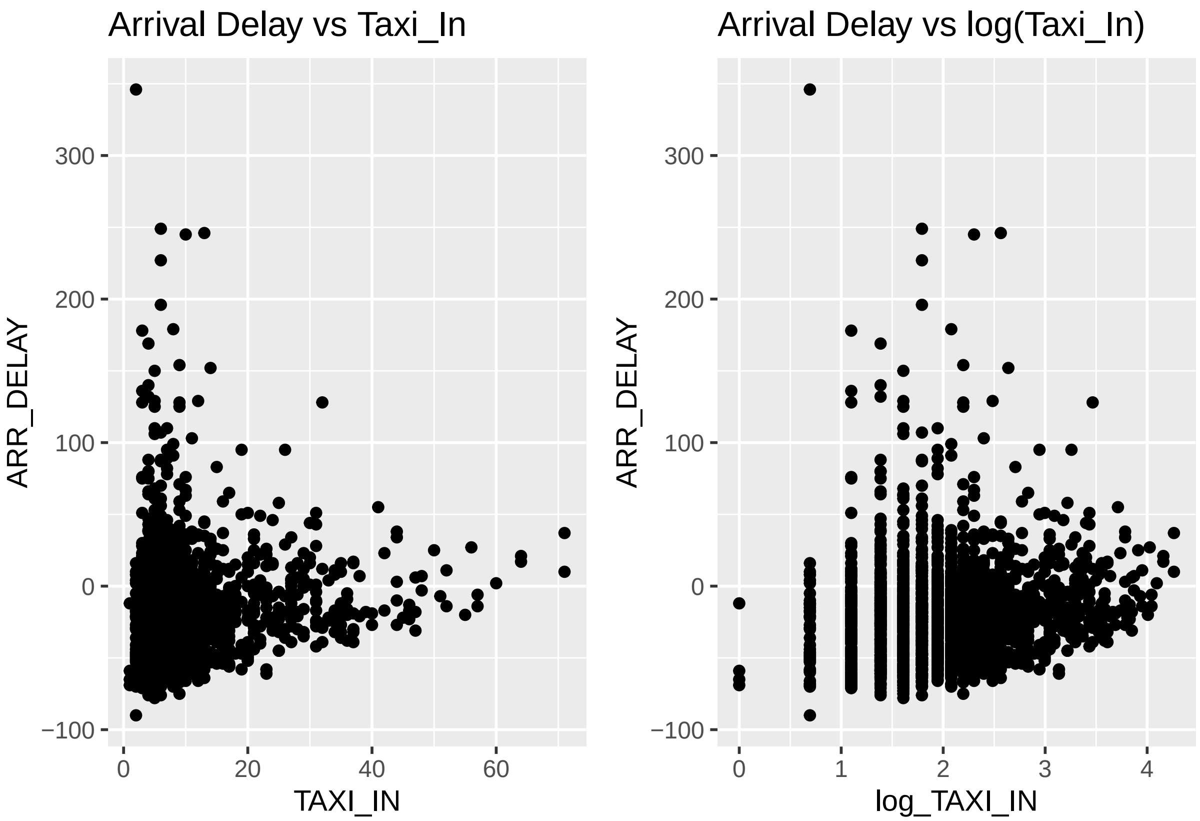
```r
# plot ARR_DELAY
pARRDELAY <- ggplot(data = flights, aes(x = ARR_DELAY)) +
  geom_histogram(binwidth = 20, fill = "#002D72", color = "#E81828", alpha = 0.8) +
  xlim(-100, 150) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "Histogram of ARR_DELAY") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

pARRDELAY
```



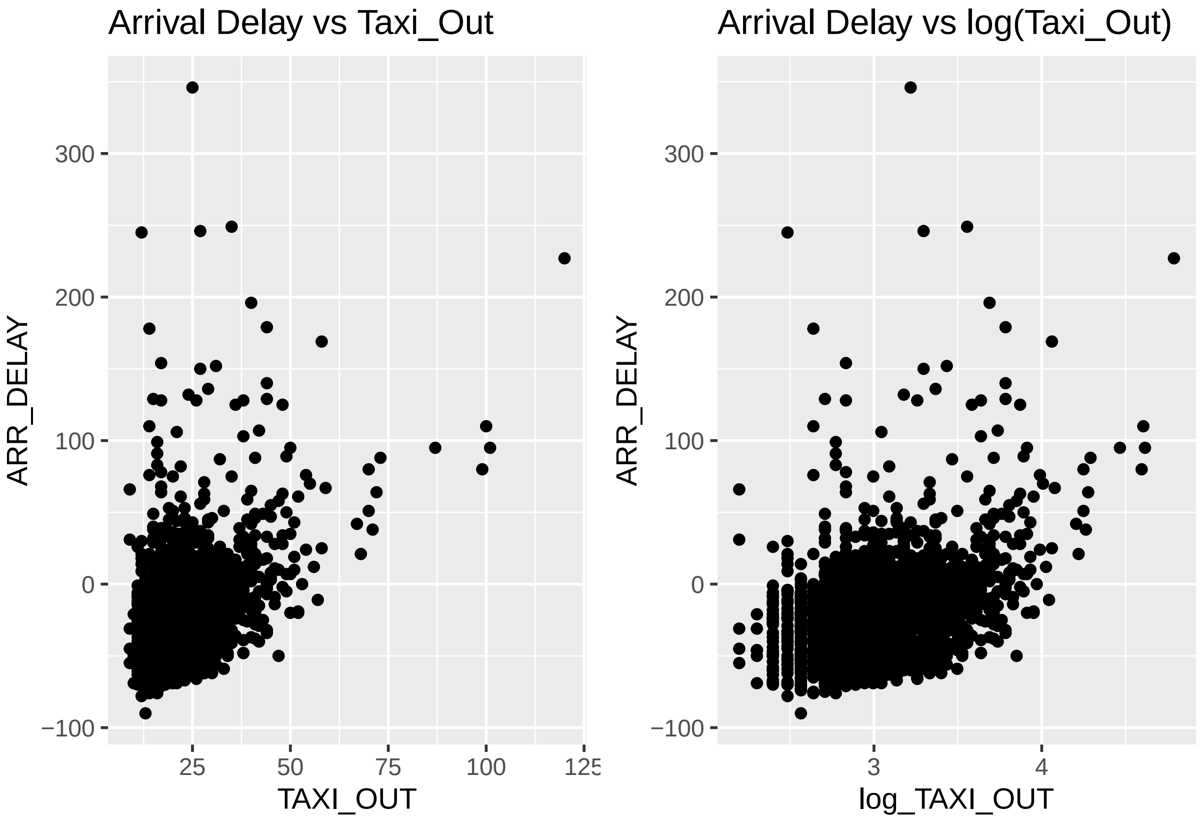
Predictors vs. Response EDA

TAXI_IN / TAXI_OUT vs. ARR_DELAY

```
p6 <- ggplot(data = flights, aes(y = ARR_DELAY, x = TAXI_IN)) +
  geom_point() +
  labs(title = "Arrival Delay vs Taxi_In")

p7 <- ggplot(data = flights, aes(y = ARR_DELAY, x = TAXI_OUT)) +
  geom_point() +
  labs(title = "Arrival Delay vs Taxi_Out")



plog6 <- ggplot(data = flights, aes(y = ARR_DELAY, x = log_TAXI_IN)) +
  geom_point() +
  labs(title = "Arrival Delay vs log(Taxi_In)")

plog7 <- ggplot(data = flights, aes(y = ARR_DELAY, x = log_TAXI_OUT)) +
  geom_point() +
  labs(title = "Arrival Delay vs log(Taxi_Out)")

p6 + plog6
```


Arrival Delay vs Taxi_In
ARR_DELAY
300
200
100
0
−100
0
20
40
60
TAXI_IN
Arrival Delay vs log(Taxi_In)
ARR_DELAY
300
200
100
0
−100
0
1
2
3
4
log_TAXI_IN

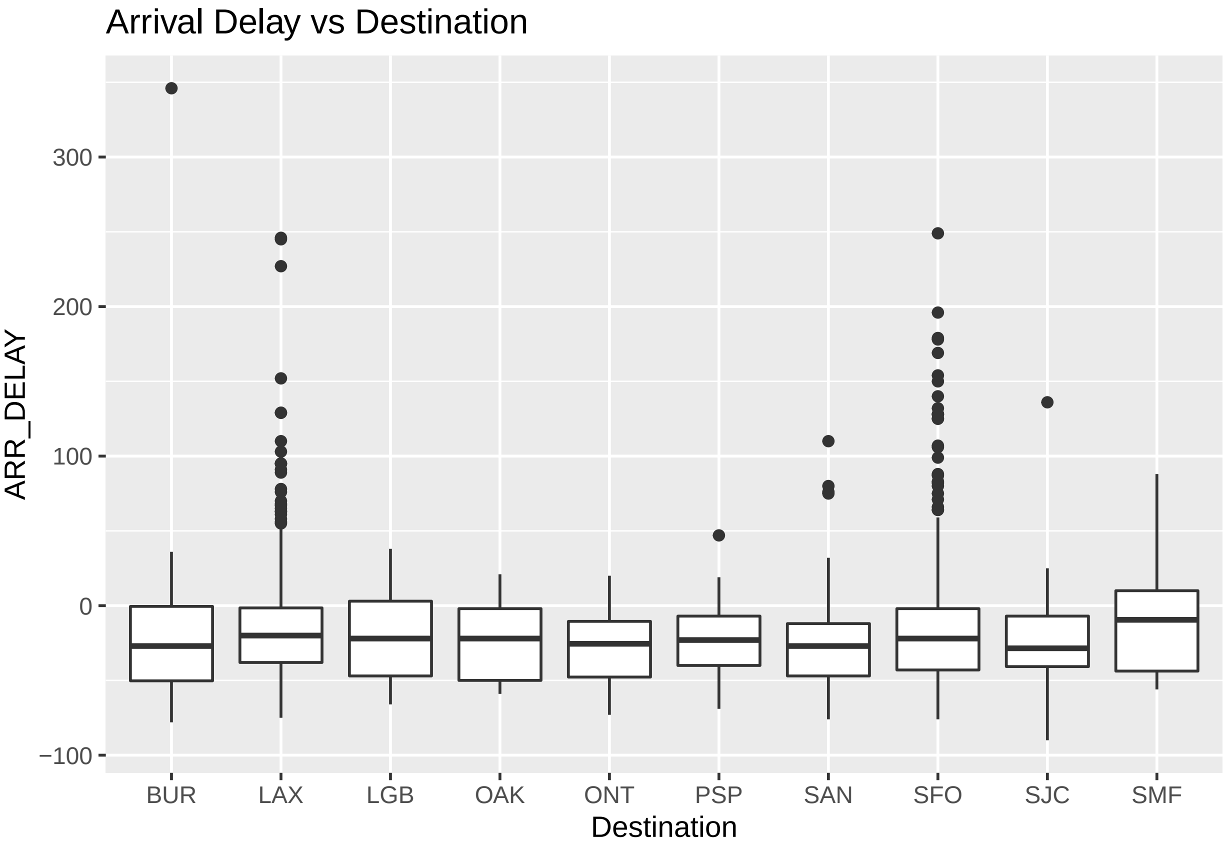
```
p7 + plog7
```


Arrival Delay vs Taxi_Out
ARR_DELAY
300
200
100
0
−100
25
50
75
100
125
TAXI_OUT
Arrival Delay vs log(Taxi_Out)
ARR_DELAY
300
200
100
0
−100
3
4
log_TAXI_OUT

These plots above suggest that we may want to transform the variables at some point.

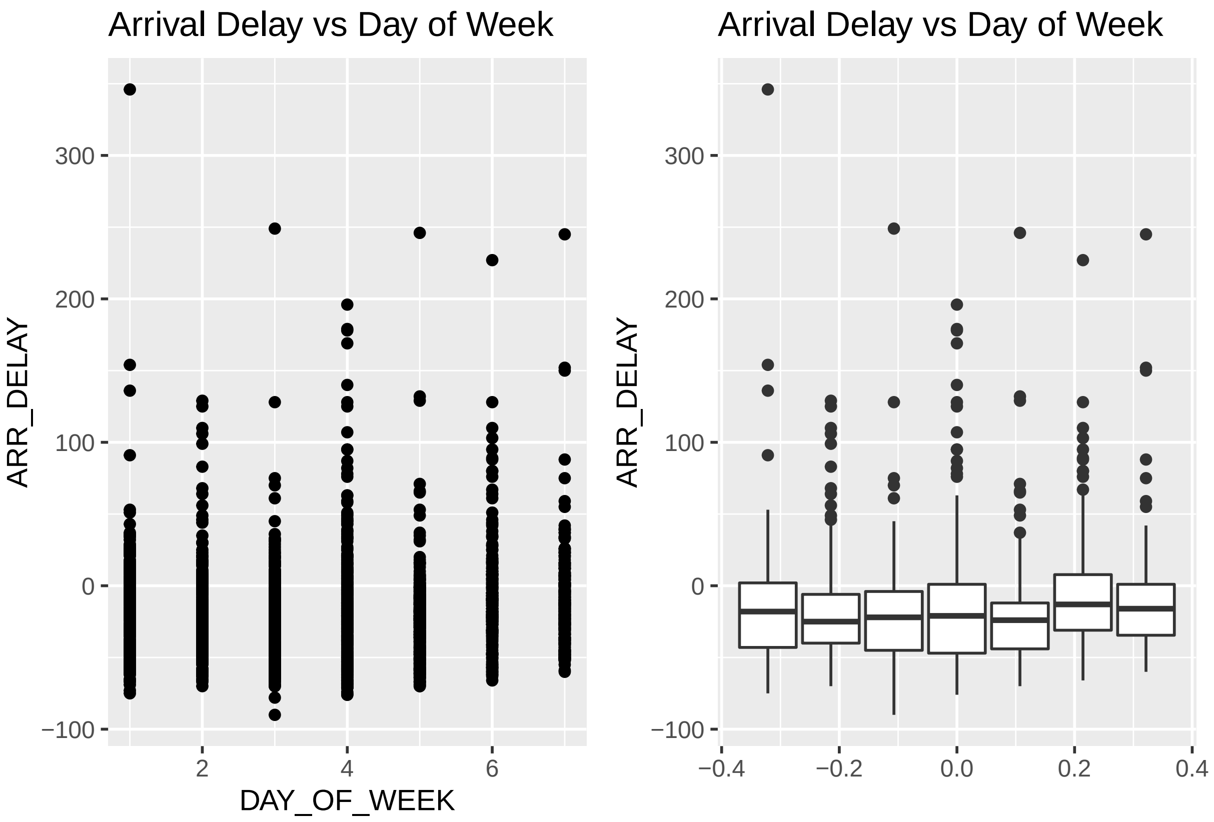
DEST vs. ARR_DELAY

```
ggplot(data = flights, aes(y = ARR_DELAY, x = DEST)) +
  geom_boxplot() +
  labs(x = "Destination",
       title = "Arrival Delay vs Destination")
```



DAY_OF_WEEK vs. ARR_DELAY

```
p8 <- ggplot(data = flights, aes(y = ARR_DELAY, x = DAY_OF_WEEK)) +
  geom_point() +
  labs(title = "Arrival Delay vs Day of Week")

p9 <- ggplot(data = flights, aes(y = ARR_DELAY, group = DAY_OF_WEEK)) +
  geom_boxplot() +
  labs(title = "Arrival Delay vs Day of Week")

p8 + p9
```

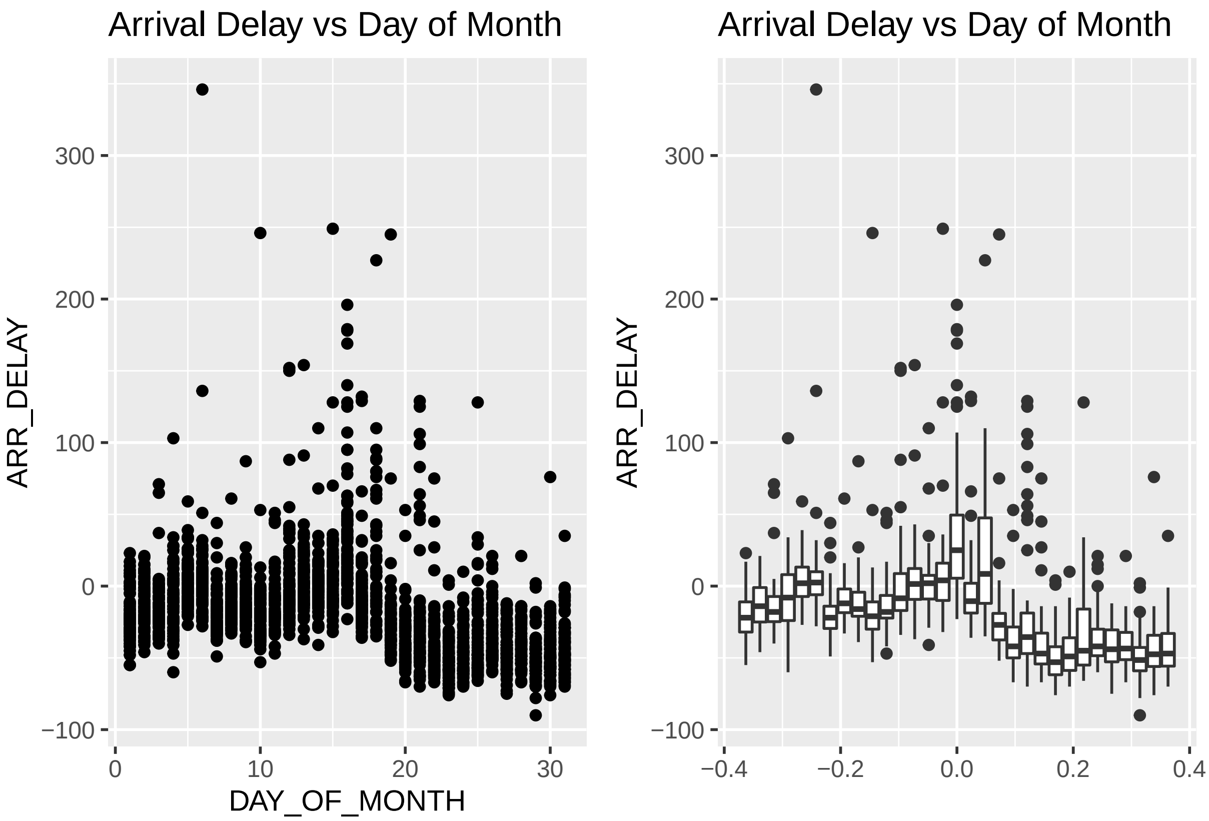


Arrival Delay vs Day of Week

Arrival Delay vs Day of Week

ARR_DELAY and DAY_OF_MONTH

```
p10 <- ggplot(data = flights, aes(y = ARR_DELAY, x = DAY_OF_MONTH)) +
  geom_point() +
  labs(title = "Arrival Delay vs Day of Month")

p11 <- ggplot(data = flights, aes(y = ARR_DELAY, group = DAY_OF_MONTH)) +
  geom_boxplot() +
  labs(title = "Arrival Delay vs Day of Month")

p10 + p11
```

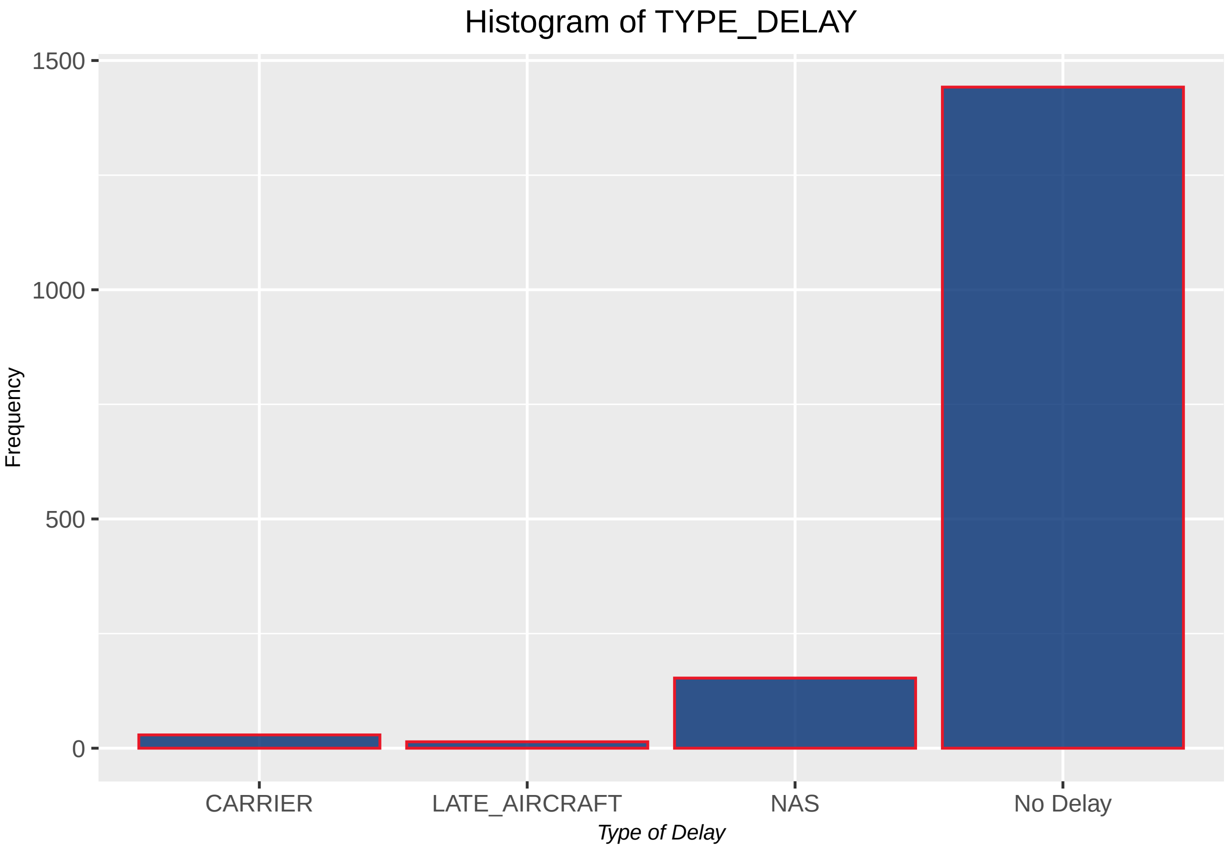

Arrival Delay vs Day of Month
ARR_DELAY
300
200
100
0
−100
0
10
20
30
DAY_OF_MONTH
Arrival Delay vs Day of Month
ARR_DELAY
300
200
100
0
−100
−0.4
−0.2
0.0
0.2
0.4

Additional Data Cleaning

New Bounds and Variable

```
# take only SFO/LAX since all 4 carriers fly there
# create TYPE_DELAY as a factor variable for type of delays
flights <- flights %>%
  filter(DEST == "SFO" | DEST == "LAX") %>%
  mutate(TYPE_DELAY = case_when(NAS_DELAY == 1 ~ "NAS",
                               CARRIER_DELAY == 1 ~ "CARRIER",
                               LATE_AIRCRAFT_DELAY == 1 ~ "LATE_AIRCRAFT",
                               WEATHER_DELAY == 1 ~ "WEATHER",
                               TRUE ~ "No Delay"))
```

```
pTYPE <- ggplot(data = flights, aes(x = TYPE_DELAY)) +
  geom_bar(fill = "#002D72", color = "#E81828", alpha = 0.8) +
  labs(x = "Type of Delay",
       y = "Frequency",
       title = "Histogram of TYPE_DELAY") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

pTYPE
```



Test and Training Set Split

We will use a 80-20 split of training and test sets.

```r
set.seed(1234)

flights <- flights %>%
  dplyr::mutate(id = row_number())

train <- flights %>%
  sample_frac(0.8)
test <- anti_join(flights, train, by = "id")
```

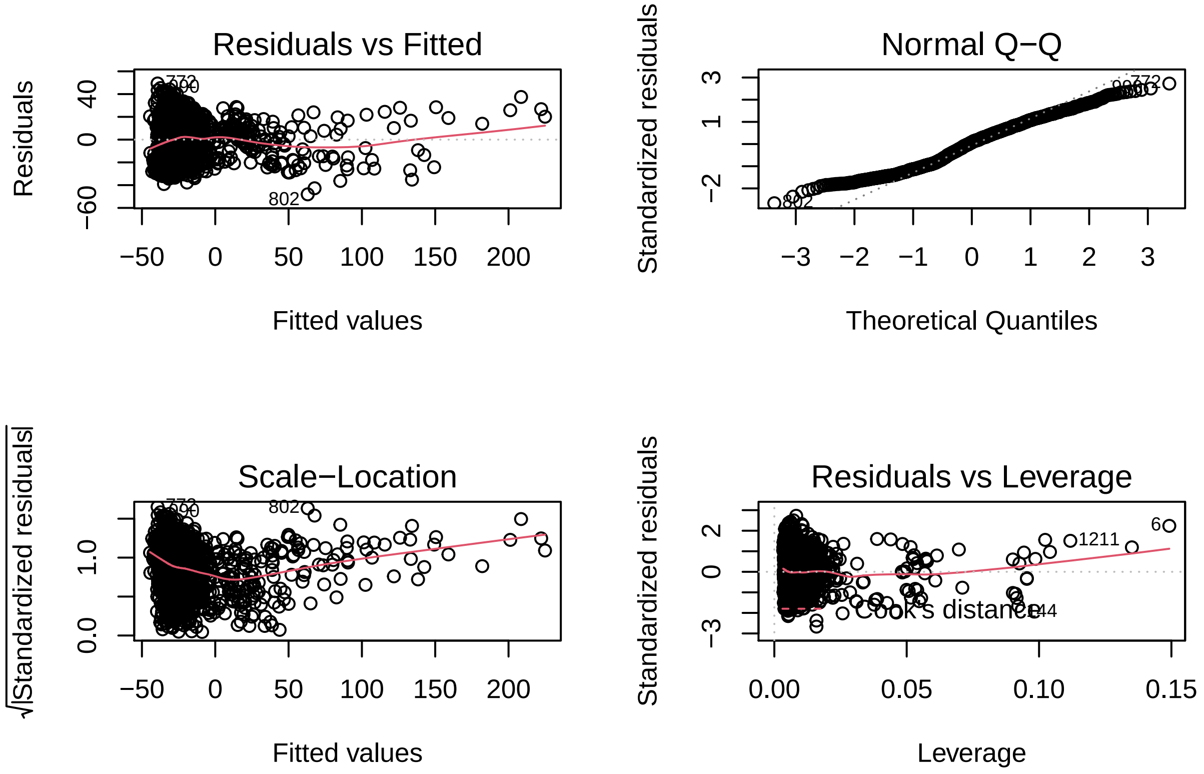
Modeling

(1) Multiple Linear Regression

(a) Baesline Linear Model (with AIC Selection)

```
# create linear model with all revelant variables
full_model <- lm(ARR_DELAY ~
                    DEP_DELAY +
                    DAY_OF_WEEK +
                    OP_CARRIER +
                    DEST +
                    CRS_DEP_TIME +
                    CRS_ARR_TIME +
                    TAXI_OUT +
                    TAXI_IN +
                    TYPE_DELAY, train)

# summary(full_model)
```

```
# use AIC model selection on full model
step_model <- stepAIC(full_model, trace = FALSE)
#summary(step_model)

# update full model
plain_linear_model <- step_model

# plot full model
par(mfrow = c(2,2))
plot(plain_linear_model)
```



(b) Full Log-Transformed Model

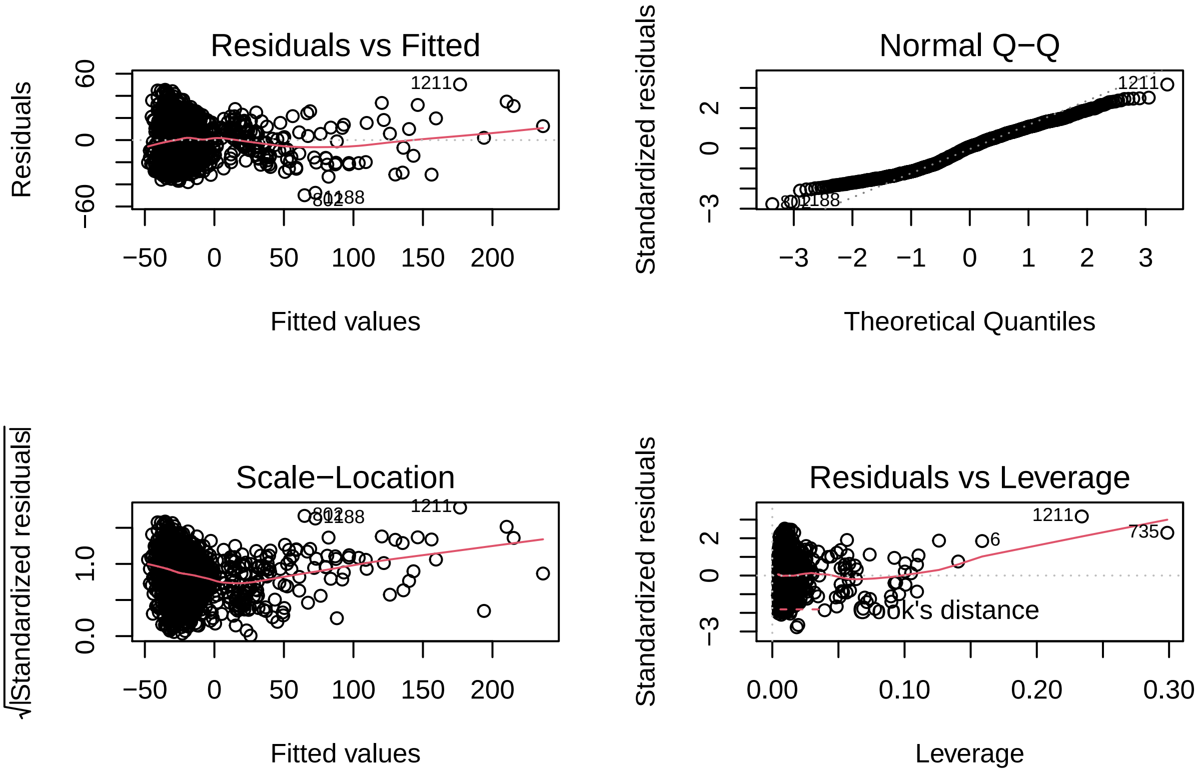
```
# fitting models and running ANOVA tests to identify interactions

## first model
lm.01 <- lm(ARR_DELAY ~ DEP_DELAY + DAY_OF_WEEK + OP_CARRIER + DEST + CRS_DEP_TIME + CRS_ARR_TIME + log_
#plot(lm.01)
#summary(lm.01)

## second model
step_model <- stepAIC(lm.01, direction = "backward", trace = FALSE)
#summary(step_model)

## third model
lm.02 <- lm(ARR_DELAY ~ DEP_DELAY + OP_CARRIER + DEST + CRS_DEP_TIME  + log_TAXI_OUT + log_TAXI_IN + TYP
#summary(lm.02)
#anova(step_model, lm.02)

## fourth model
lm.03 <- lm(ARR_DELAY ~ DEP_DELAY + OP_CARRIER + DEST + CRS_DEP_TIME  + log_TAXI_OUT + log_TAXI_IN + TYP
#anova(lm.02, lm.03)

## final log model
log_linear_model <- lm(ARR_DELAY ~ DEP_DELAY + OP_CARRIER + DEST + CRS_DEP_TIME  + log_TAXI_OUT + log_TA

anova(lm.03, log_linear_model)
```

```
## Analysis of Variance Table
##
## Model 1: ARR_DELAY ~ DEP_DELAY + OP_CARRIER + DEST + CRS_DEP_TIME + log_TAXI_OUT +
##     log_TAXI_IN + TYPE_DELAY + OP_CARRIER:DEST + DEST:log_TAXI_IN
## Model 2: ARR_DELAY ~ DEP_DELAY + OP_CARRIER + DEST + CRS_DEP_TIME + log_TAXI_OUT +
##     log_TAXI_IN + TYPE_DELAY + OP_CARRIER:DEST + DEST:log_TAXI_IN +
##     log_TAXI_OUT:DEP_DELAY
##   Res.Df    RSS Df Sum of Sq      F  Pr(>F)
## 1   1294 427667
## 2   1293 425449  1      2218 6.7408 0.00953 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
summary(log_linear_model)
```

```
##
## Call:
## lm(formula = ARR_DELAY ~ DEP_DELAY + OP_CARRIER + DEST + CRS_DEP_TIME +
##     log_TAXI_OUT + log_TAXI_IN + TYPE_DELAY + OP_CARRIER:DEST +
##     DEST:log_TAXI_IN + log_TAXI_OUT:DEP_DELAY, data = train)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -49.817 -15.330   1.198  13.897  50.301
##
## Coefficients:
##                           Estimate Std. Error t value Pr(>|t|)
## (Intercept)             -81.901399   7.262197 -11.278  < 2e-16 ***
## DEP_DELAY                   0.524207    0.141256   3.711 0.000215 ***
## OP_CARRIERAS               -4.458249    2.087733  -2.135 0.032912 *
## OP_CARRIERB6                5.045463    1.669832   3.022 0.002564 **
## OP_CARRIERDL               -1.493672    1.717998  -0.869 0.384775
## DESTSFO                     9.893184    4.366882   2.266 0.023647 *
## CRS_DEP_TIME               -0.004364    0.001070  -4.081 4.77e-05 ***
## log_TAXI_OUT               20.610508    1.617078  12.746  < 2e-16 ***
## log_TAXI_IN                 8.433233    1.057392   7.976 3.32e-15 ***
## TYPE_DELAYLATE_AIRCRAFT    -3.973566    6.537317  -0.608 0.543408
## TYPE_DELAYNAS              24.019795    4.598524   5.223 2.05e-07 ***
## TYPE_DELAYNo Delay        -15.676745    4.540377  -3.453 0.000573 ***
## OP_CARRIERAS:DESTSFO        6.630276    3.374581   1.965 0.049655 *
## OP_CARRIERB6:DESTSFO       -4.199151    2.858830  -1.469 0.142121
## OP_CARRIERDL:DESTSFO       -1.424895    2.900122  -0.491 0.623282
## DESTSFO:log_TAXI_IN        -5.261163    1.951509  -2.696 0.007110 **
## DEP_DELAY:log_TAXI_OUT      0.113332    0.043651   2.596 0.009530 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 18.14 on 1293 degrees of freedom
## Multiple R-squared:  0.7376, Adjusted R-squared:  0.7344
## F-statistic: 227.2 on 16 and 1293 DF,  p-value: < 2.2e-16
```

```r
par(mfrow = c(2,2))
plot(log_linear_model)
```



(c) Box-Cox-Transformed Response (w/o Log-Transformed Predictors)

```r
# adjust response with vertical shift to account for negative responses
## min(train$ARR_DELAY) = -74 --> shift up by constant 75

## transform repsonse
train$adj_ARR_DELAY = train$ARR_DELAY + 75

## fit lm for future Box-Cox use
adj_linear_model <- lm(adj_ARR_DELAY ~
                    DEP_DELAY +
                     OP_CARRIER +
                     DEST +
                     CRS_DEP_TIME +
                     CRS_ARR_TIME +
                     TAXI_OUT +
                     TAXI_IN +
                     TYPE_DELAY,
                   data = train)
```

Box-Cox Setup

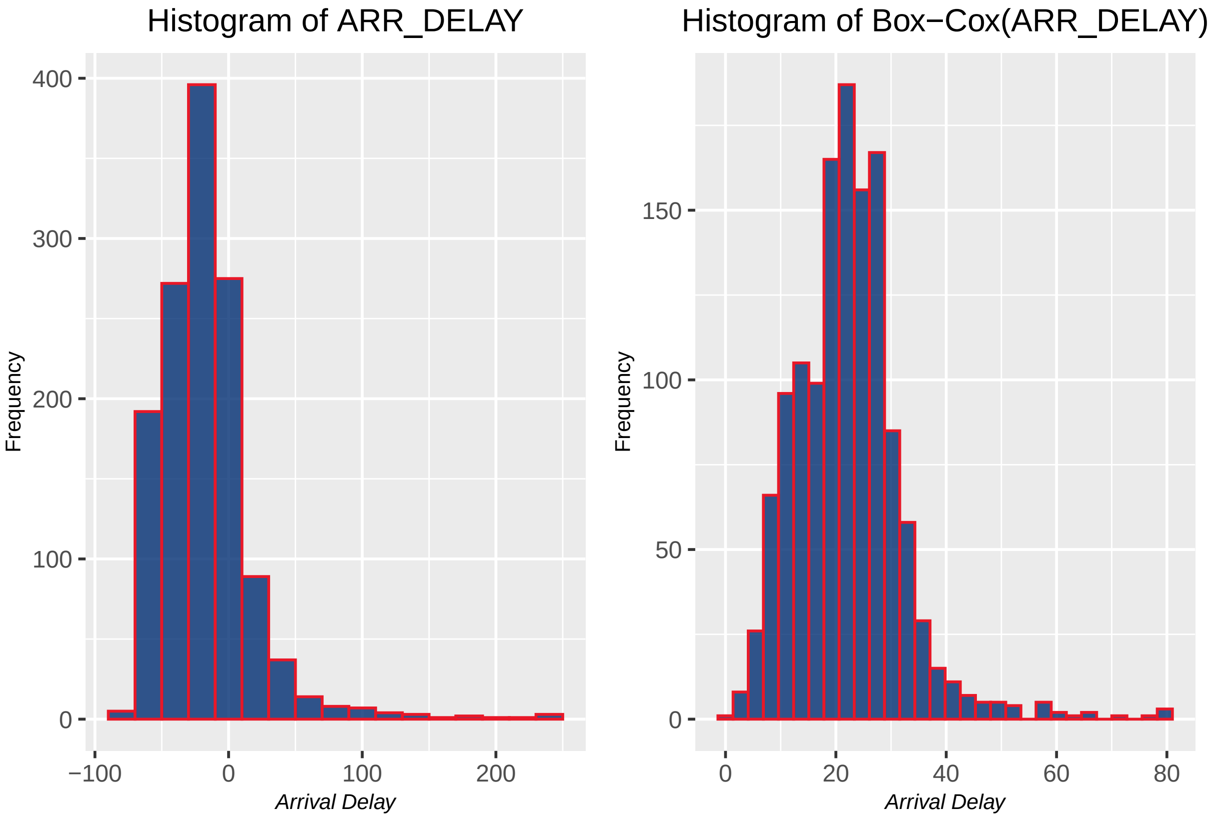
```r
# box cox transform (same as case study)
## call EnvStats library
bc_model <- EnvStats::boxcox(adj_linear_model, optimize = TRUE)
# find optimal lambda parameter
bc_lambda <- bc_model$lambda
bc_lambda
```

```
## [1] 0.6981342
```

```r
#plot(bc_model)
```

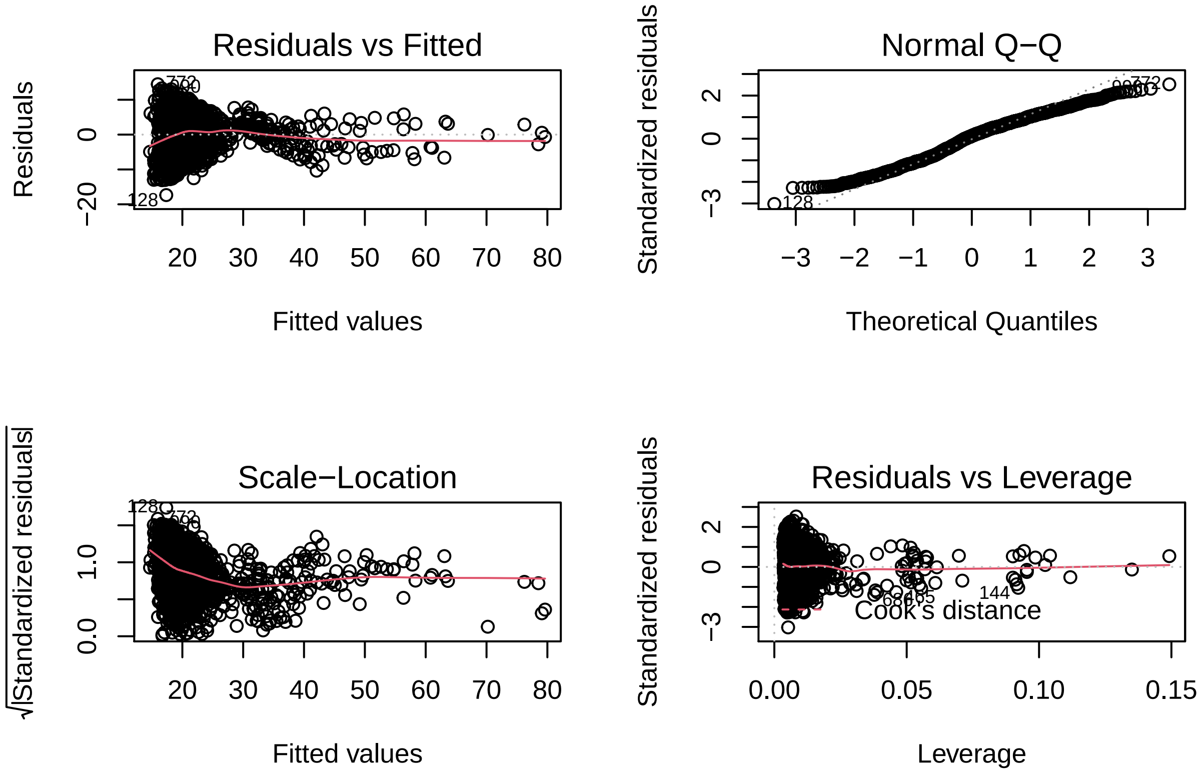
```r
# add Box-Cox response as variable to train set
train <- train %>%
  mutate(bc_adj_ARR_DELAY = ((adj_ARR_DELAY^bc_lambda) - 1)/bc_lambda)

# plot training ARR_DELAY
ptrain_ARRDELAY <- ggplot(data = train, aes(x = ARR_DELAY)) +
  geom_histogram(binwidth = 20, fill = "#002D72", color = "#E81828", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "Histogram of ARR_DELAY") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# plot Box-Cox training ARR_DELAY
ptrain_bcARRDELAY <- ggplot(data = train, aes(x = bc_adj_ARR_DELAY)) +
  geom_histogram(fill = "#002D72", color = "#E81828", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "Histogram of Box-Cox(ARR_DELAY)") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

ptrain_ARRDELAY + ptrain_bcARRDELAY
```

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



Final Box-Cox Linear Model

```
bc_adj_linear_model <- lm(bc_adj_ARR_DELAY ~
                    DEP_DELAY +
                     OP_CARRIER +
                     DEST +
                     CRS_DEP_TIME +
                     CRS_ARR_TIME +
                     TAXI_OUT +
                     TAXI_IN +
                     TYPE_DELAY,
                   data = train)
par(mfrow = c(2,2))
plot(bc_adj_linear_model)
```



```r
summary(bc_adj_linear_model)
```

```
##
## Call:
## lm(formula = bc_adj_ARR_DELAY ~ DEP_DELAY + OP_CARRIER + DEST +
##     CRS_DEP_TIME + CRS_ARR_TIME + TAXI_OUT + TAXI_IN + TYPE_DELAY,
##     data = train)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -17.3550  -4.6040   0.7628   4.3532  14.4500
##
## Coefficients:
##                           Estimate Std. Error t value Pr(>|t|)
## (Intercept)             21.9473168  1.5511418  14.149  < 2e-16 ***
## DEP_DELAY                0.2019174  0.0085684  23.565  < 2e-16 ***
## OP_CARRIERAS            -0.3865039  0.5255208  -0.735 0.462187
## OP_CARRIERB6             0.4703869  0.4324730   1.088 0.276944
## OP_CARRIERDL            -0.3934861  0.4383847  -0.898 0.369575
## DESTSFO                 -0.6403901  0.3426977  -1.869 0.061894 .
## CRS_DEP_TIME            -0.0012308  0.0003474  -3.543 0.000410 ***
## CRS_ARR_TIME            -0.0005199  0.0002776  -1.873 0.061325 .
## TAXI_OUT                 0.2468133  0.0192961  12.791  < 2e-16 ***
## TAXI_IN                  0.1470986  0.0194304   7.571 7.02e-14 ***
## TYPE_DELAYLATE_AIRCRAFT -0.9730558  2.0594731  -0.472 0.636665
## TYPE_DELAYNAS            5.1595880  1.4211386   3.631 0.000294 ***
## TYPE_DELAYNo Delay      -5.5980132  1.4072197  -3.978 7.33e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

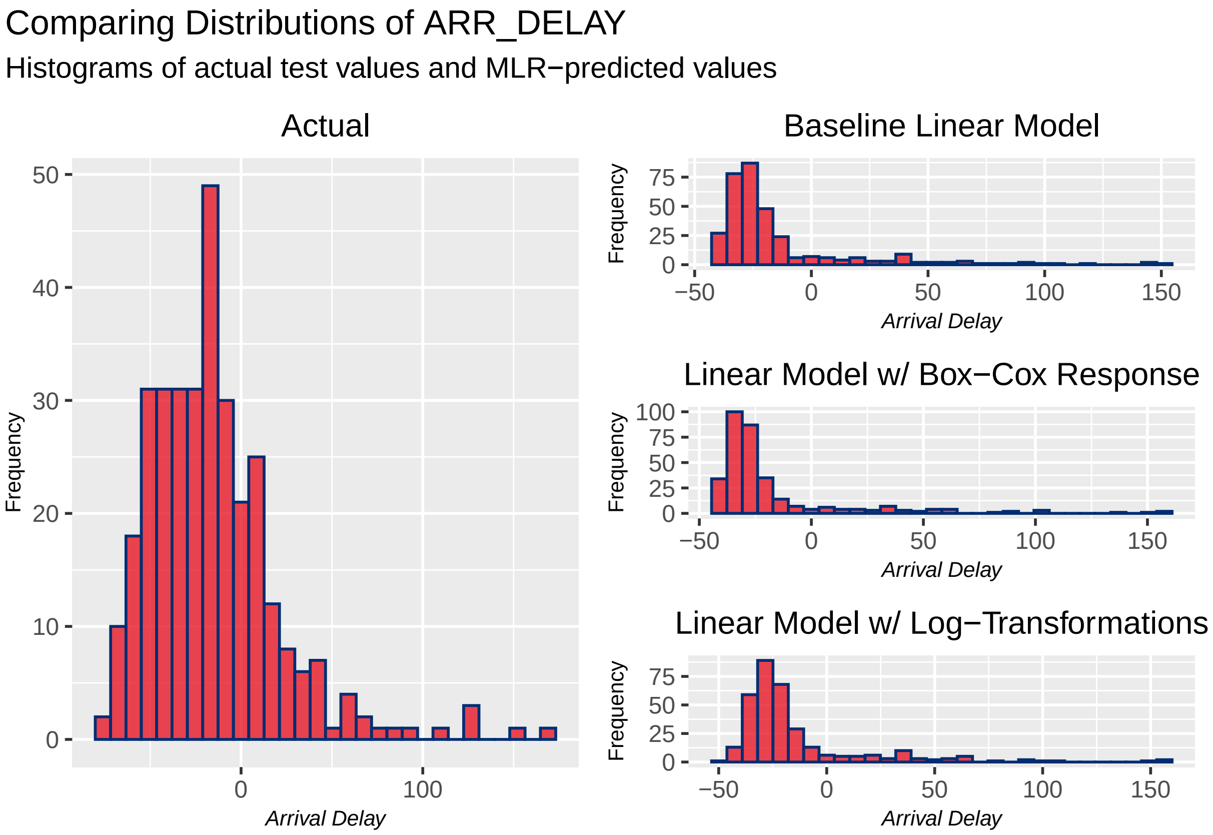
```
##
## Residual standard error: 5.755 on 1297 degrees of freedom
## Multiple R-squared:  0.6445, Adjusted R-squared:  0.6412
## F-statistic: 195.9 on 12 and 1297 DF,  p-value: < 2.2e-16
```

MLR Test Error Metrics & Predictions

LOOKING AT: - model without any interactions or transformations: ENDED UP PERFORMING THE BEST!!! - log transformed predictors (taxi_in and taxi_out), interactions, no boxcox transformed response - box-cox transformed response, no interactions or predicted transformations

```r
# predictions
## baseline
test$plain_mlr_pred <- predict(plain_linear_model, test)
## log
test$log_linear_preds <- predict(log_linear_model, test)
## bc
test$adj_ARR_DELAY = test$ARR_DELAY + 77
test$bc_adj_linear_preds <- predict(bc_adj_linear_model, test)
test <- test %>%
 mutate(adj_linear_preds = ((bc_adj_linear_preds*(bc_lambda) + 1)^(1/bc_lambda)))
test$bc_mlr_pred = test$adj_linear_preds - 77

## histogram of predictions vs. actual
# actual ARR_DELAY in test set
#hist(test$ARR_DELAY)
ptest_actual <- ggplot(data = test, aes(x = ARR_DELAY)) +
  geom_histogram(fill = "#E81828", color = "#002D72", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "Actual") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# predicted ARR_DELAY in test set -- baseline lm
ptest_baseline_preds <- ggplot(data = test, aes(x = plain_mlr_pred)) +
  geom_histogram(fill = "#E81828", color = "#002D72", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "Baseline Linear Model") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# predicted ARR_DELAY in test set -- lm with log-trans
# hist(test$log_linear_preds)
ptest_lm_log_preds <- ggplot(data = test, aes(x = log_linear_preds)) +
  geom_histogram(fill = "#E81828", color = "#002D72", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "Linear Model w/ Log-Transformations") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# predicted ARR_DELAY in test set -- lm with Box-Cox model
#hist(test$log_linear_preds)
ptest_bc_preds <- ggplot(data = test, aes(x = bc_mlr_pred)) +
  geom_histogram(fill = "#E81828", color = "#002D72", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "Linear Model w/ Box-Cox Response") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

mlr_patchwork <- ptest_actual + (ptest_baseline_preds / ptest_bc_preds / ptest_lm_log_preds)

mlr_patchwork + plot_annotation(
  title = 'Comparing Distributions of ARR_DELAY',
  subtitle = 'Histograms of actual test values and MLR-predicted values'
)
```

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



```
# test MSE calculations
plain_linear_model_MSE <- sum((test$ARR_DELAY - test$plain_mlr_pred)^2, na.rm=T)/length(test$ARR_DELAY)
plain_linear_model_MSE
```

```
## [1] 322.4588
```

```
log_linear_MSE <- sum((test$log_linear_preds-test$ARR_DELAY)^2, na.rm=T)/length(test$ARR_DELAY)
log_linear_MSE
```

```
## [1] 333.8962
```

```
bc_adj_linear_model_MSE <- sum((test$ARR_DELAY - test$bc_mlr_pred)^2, na.rm=T)/length(test$ARR_DELAY)
bc_adj_linear_model_MSE
```

```
## [1] 334.9226
```

(2) Generalized Additive Models

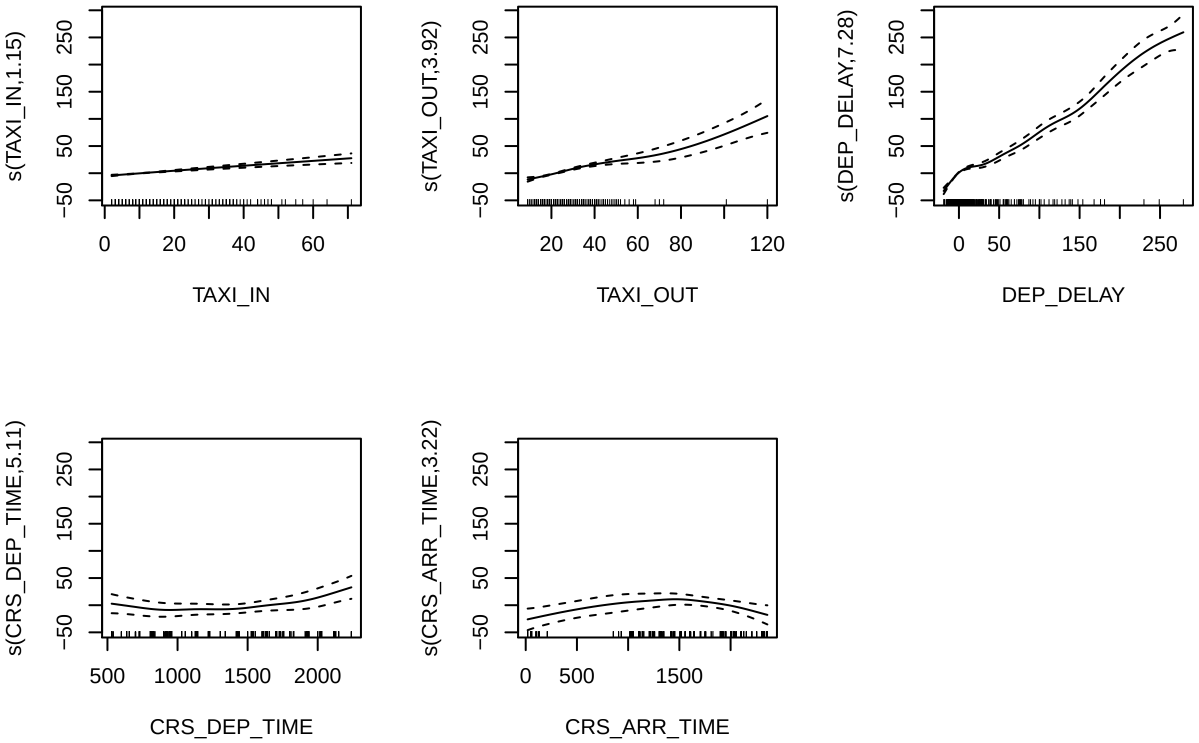
(a) Initial GAM: No Box-Cox on Response

```
gam00 <- gam(ARR_DELAY ~ DAY_OF_WEEK +
                   OP_CARRIER +
                   s(TAXI_IN) +
                   s(TAXI_OUT) +
                   DEST +
                   s(DEP_DELAY) +
                   s(CRS_DEP_TIME) +
                   s(CRS_ARR_TIME) +
                   TYPE_DELAY, data = train)

summary(gam00)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## ARR_DELAY ~ DAY_OF_WEEK + OP_CARRIER + s(TAXI_IN) + s(TAXI_OUT) +
##     DEST + s(DEP_DELAY) + s(CRS_DEP_TIME) + s(CRS_ARR_TIME) +
##     TYPE_DELAY
##
## Parametric coefficients:
##                          Estimate Std. Error t value Pr(>|t|)
## (Intercept)                0.6248     4.6488   0.134   0.8931
## DAY_OF_WEEK                0.2465     0.2625   0.939   0.3479
## OP_CARRIERAS              -1.4083     1.6722  -0.842   0.3999
## OP_CARRIERB6               2.8700     1.3616   2.108   0.0352 *
## OP_CARRIERDL              -2.7519     1.3905  -1.979   0.0480 *
## DESTSFO                   -0.5607     1.1267  -0.498   0.6188
## TYPE_DELAYLATE_AIRCRAFT   -3.3786     6.5848  -0.513   0.6080
## TYPE_DELAYNAS             18.9194     4.5466   4.161 3.38e-05 ***
## TYPE_DELAYNo Delay       -22.2130     4.5742  -4.856 1.34e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
```

```
##                    edf Ref.df       F  p-value    
## s(TAXI_IN)       1.148  1.283  44.974 6.24e-13 ***
## s(TAXI_OUT)      3.922  4.851  46.982  < 2e-16 ***
## s(DEP_DELAY)     7.279  8.272 136.783  < 2e-16 ***
## s(CRS_DEP_TIME) 5.114  6.050   2.121   0.0415 *  
## s(CRS_ARR_TIME) 3.221  3.897   1.845   0.1277    
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 
## R-sq.(adj) =  0.749   Deviance explained = 75.5%
## GCV = 317.86  Scale est. = 310.66    n = 1310
```

```r
par(mfrow = c(2,3))
plot.gam(gam00, se=TRUE)
```



Checking Lineartiy TAXI_IN may be linear

```r
gam01 <- gam(ARR_DELAY ~ DAY_OF_WEEK +
                   OP_CARRIER +
                   TAXI_IN +
                   s(TAXI_OUT) +
                   DEST +
                   s(DEP_DELAY) +
                   s(CRS_DEP_TIME) +
                   s(CRS_ARR_TIME) +
                   TYPE_DELAY, data = train)

anova(gam00, gam01, test = "F")
```

```
## Analysis of Deviance Table
## 
```

```
## Model 1: ARR_DELAY ~ DAY_OF_WEEK + OP_CARRIER + s(TAXI_IN) + s(TAXI_OUT) +
##     DEST + s(DEP_DELAY) + s(CRS_DEP_TIME) + s(CRS_ARR_TIME) +
##     TYPE_DELAY
## Model 2: ARR_DELAY ~ DAY_OF_WEEK + OP_CARRIER + TAXI_IN + s(TAXI_OUT) +
##     DEST + s(DEP_DELAY) + s(CRS_DEP_TIME) + s(CRS_ARR_TIME) +
##     TYPE_DELAY
##   Resid. Df Resid. Dev       Df Deviance      F Pr(>F)
## 1    1276.6     397738
## 2    1276.9     397845 -0.29646  -106.39 1.1552 0.1929
```

based on anova test, the model with a smoothing spline on TAXI_IN is a better fit

More ANOVA Tests DAY_OF_WEEK, DEST, and CRS_ARR_TIME have very high p-values, so let's try an anova test without including them

```
gam02 <- gam(ARR_DELAY ~ OP_CARRIER +
                   s(TAXI_IN) +
                   s(TAXI_OUT) +
                   s(DEP_DELAY) +
                   s(CRS_DEP_TIME) +
                   TYPE_DELAY, data = train)

anova(gam00, gam02, test = "F")
```

```
## Analysis of Deviance Table
##
## Model 1: ARR_DELAY ~ DAY_OF_WEEK + OP_CARRIER + s(TAXI_IN) + s(TAXI_OUT) +
##     DEST + s(DEP_DELAY) + s(CRS_DEP_TIME) + s(CRS_ARR_TIME) +
##     TYPE_DELAY
## Model 2: ARR_DELAY ~ OP_CARRIER + s(TAXI_IN) + s(TAXI_OUT) + s(DEP_DELAY) +
##     s(CRS_DEP_TIME) + TYPE_DELAY
##   Resid. Df Resid. Dev      Df Deviance      F  Pr(>F)
## 1    1276.6     397738
## 2    1280.0     400550 -3.3459  -2811.2 2.7045 0.03822 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

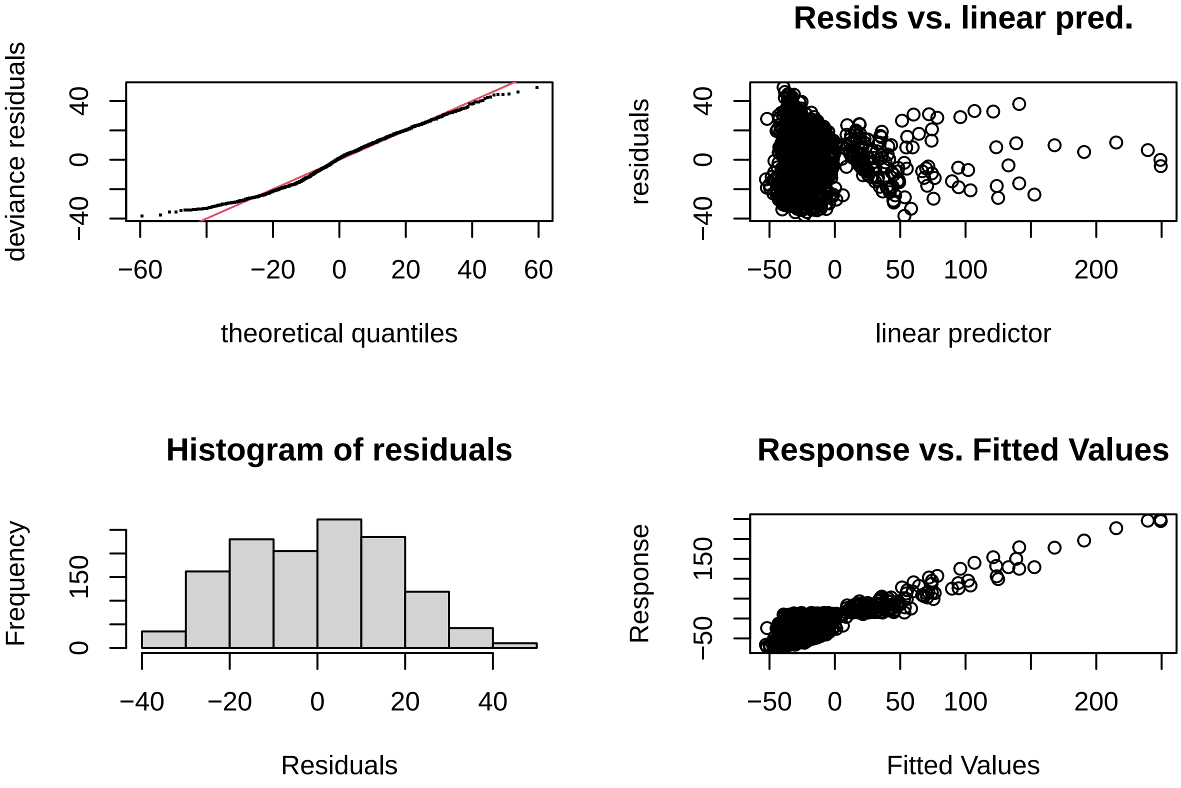
based on the anova test, the model excluding these variables is a better fit

Tuned Initial GAM

```
# final fit
summary(gam02)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## ARR_DELAY ~ OP_CARRIER + s(TAXI_IN) + s(TAXI_OUT) + s(DEP_DELAY) +
##     s(CRS_DEP_TIME) + TYPE_DELAY
##
## Parametric coefficients:
##                           Estimate Std. Error t value Pr(>|t|)
## (Intercept)                  1.828      4.530   0.404   0.6865
## OP_CARRIERAS                -1.676      1.664  -1.007   0.3140
## OP_CARRIERB6               2.486      1.354   1.836   0.0666 .
## OP_CARRIERDL              -3.137      1.381  -2.272   0.0233 *
## TYPE_DELAYLATE_AIRCRAFT   -3.199      6.601  -0.485   0.6281
## TYPE_DELAYNAS             18.795      4.556   4.126 3.93e-05 ***
## TYPE_DELAYNo Delay       -22.413      4.588  -4.885 1.16e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                  edf Ref.df       F  p-value
## s(TAXI_IN)     1.260  1.478  43.326 7.39e-14 ***
## s(TAXI_OUT)    4.308  5.298  44.490  < 2e-16 ***
## s(DEP_DELAY)   7.384  8.348 134.478  < 2e-16 ***
## s(CRS_DEP_TIME) 6.781  7.883   5.229 2.36e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.748   Deviance explained = 75.3%
## GCV = 318.64  Scale est. = 312.13    n = 1310
```

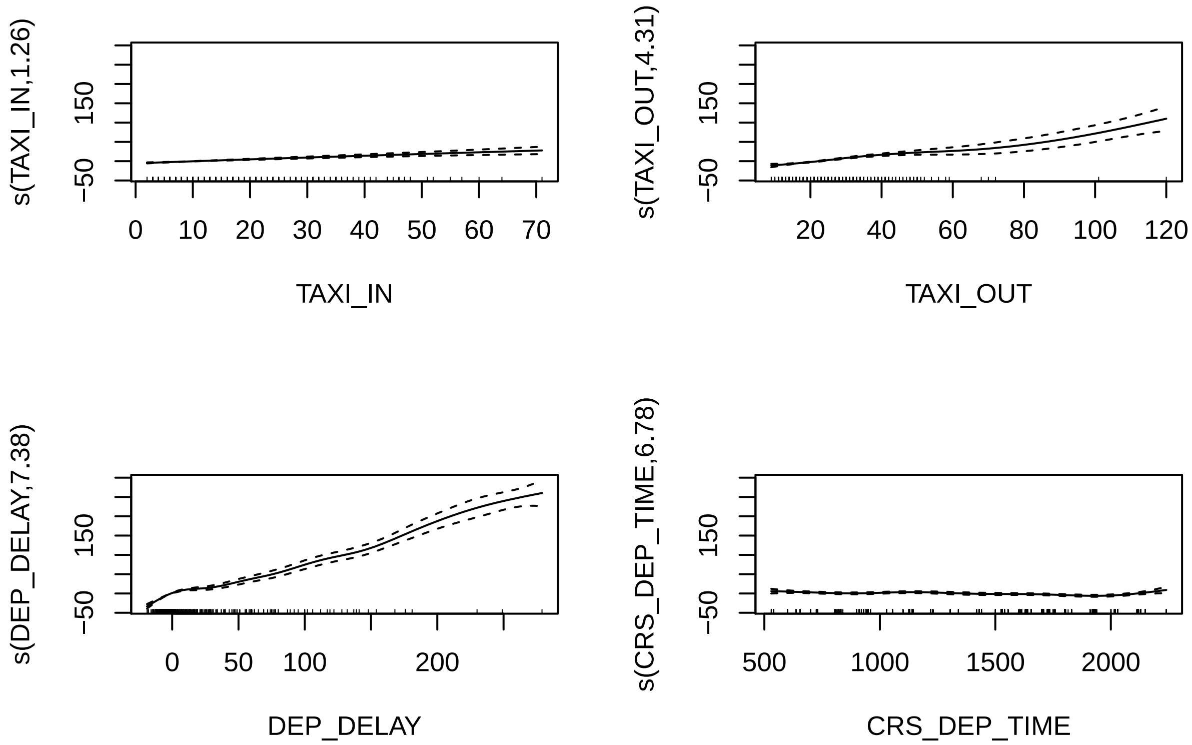
```
# diagnostic plots
par(mfrow = c(2,2))
gam.check(gam02)
```



```
##
## Method: GCV   Optimizer: magic
## Smoothing parameter selection converged after 12 iterations.
## The RMS GCV score gradient at convergence was 0.0007156955 .
## The Hessian was positive definite.
## Model rank =  43 / 43
```

```
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                   k'  edf k-index p-value
## s(TAXI_IN)      9.00 1.26    0.99    0.32
## s(TAXI_OUT)     9.00 4.31    1.07    0.99
## s(DEP_DELAY)    9.00 7.38    0.99    0.31
## s(CRS_DEP_TIME) 9.00 6.78    0.97    0.14
```

```r
# predictor plots
par(mfrow = c(2,2))
plot(gam02)
```



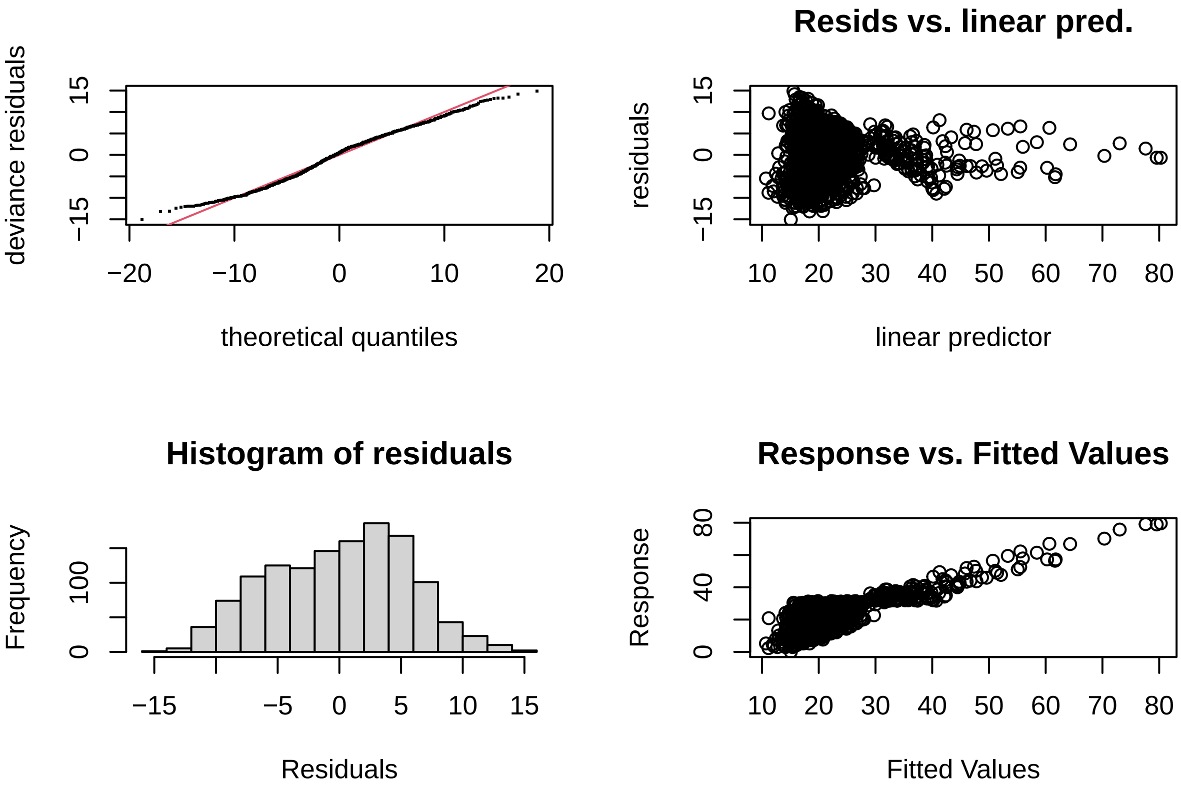
(b) Secondary GAM: Box-Cox on Response

```r
gambc <- gam(bc_adj_ARR_DELAY ~ OP_CARRIER +
                   s(TAXI_IN) +
                   s(TAXI_OUT) +
                   s(DEP_DELAY) +
                   s(CRS_DEP_TIME) +
                   TYPE_DELAY, data = train)

# final BC GAM fit
summary(gambc)
```

```
##
## Family: gaussian
## Link function: identity
##
```

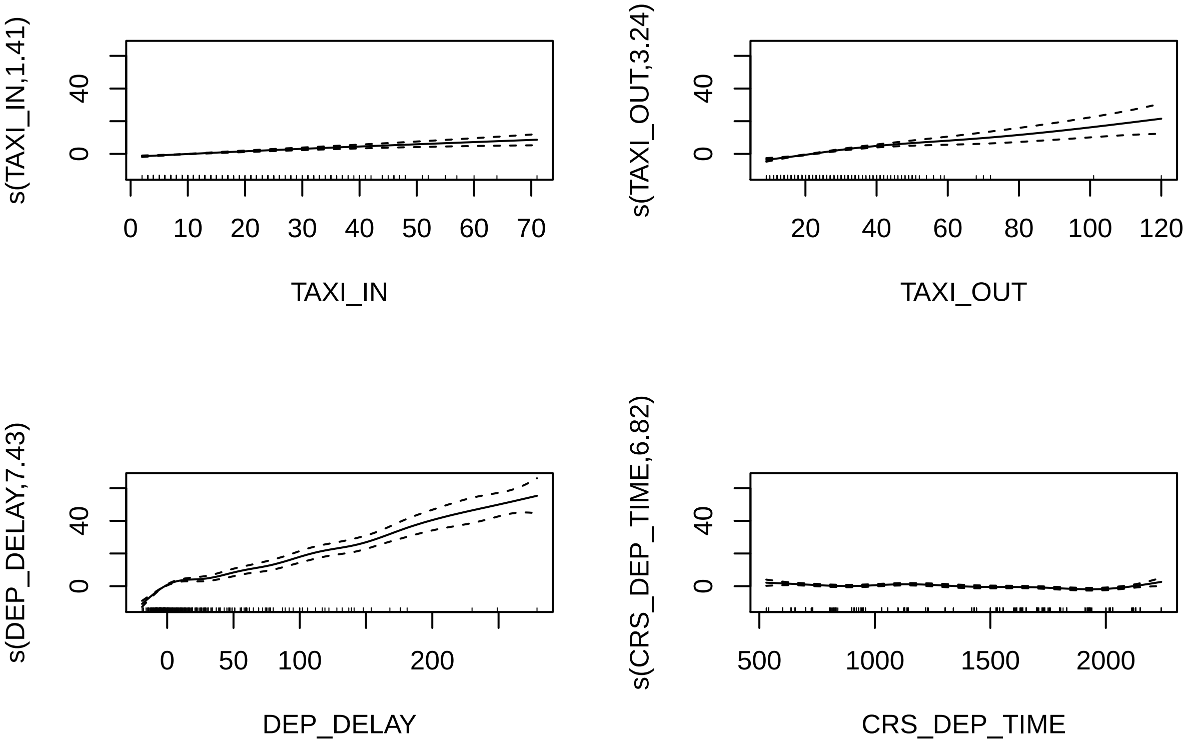
```
## Formula:
## bc_adj_ARR_DELAY ~ OP_CARRIER + s(TAXI_IN) + s(TAXI_OUT) + s(DEP_DELAY) +
##     s(CRS_DEP_TIME) + TYPE_DELAY
##
## Parametric coefficients:
##                          Estimate Std. Error t value Pr(>|t|)
## (Intercept)               28.2676     1.4315  19.747  < 2e-16 ***
## OP_CARRIERAS              -0.5081     0.5258  -0.966  0.33407
## OP_CARRIERB6               0.7942     0.4274   1.858  0.06340 .
## OP_CARRIERDL              -0.9164     0.4365  -2.099  0.03598 *
## TYPE_DELAYLATE_AIRCRAFT  -1.0708     2.0884  -0.513  0.60822
## TYPE_DELAYNAS              3.9305     1.4402   2.729  0.00644 **
## TYPE_DELAYNo Delay        -7.1098     1.4502  -4.903 1.07e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                   edf Ref.df      F  p-value
## s(TAXI_IN)      1.409  1.721 38.501 2.66e-14 ***
## s(TAXI_OUT)     3.241  4.048 46.660  < 2e-16 ***
## s(DEP_DELAY)    7.435  8.383 76.964  < 2e-16 ***
## s(CRS_DEP_TIME) 6.825  7.920  5.521 8.48e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.662   Deviance explained = 66.8%
## GCV = 31.856  Scale est. = 31.226    n = 1310
```

```r
# diagnostic plots
par(mfrow = c(2,2))
gam.check(gambc)
```



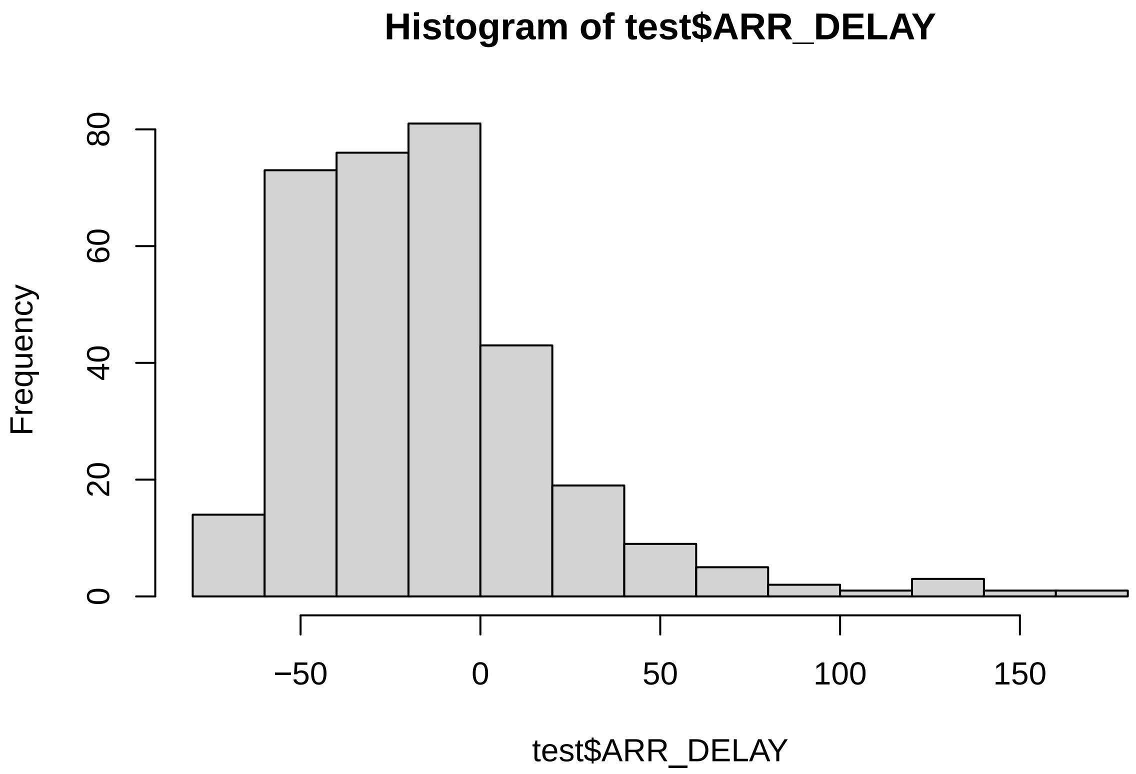
```
##
## Method: GCV   Optimizer: magic
## Smoothing parameter selection converged after 11 iterations.
## The RMS GCV score gradient at convergence was 0.0002369166 .
## The Hessian was positive definite.
## Model rank =  43 / 43
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                   k'  edf k-index p-value
## s(TAXI_IN)      9.00 1.41    0.99    0.36
## s(TAXI_OUT)     9.00 3.24    1.06    0.98
## s(DEP_DELAY)    9.00 7.43    0.98    0.23
## s(CRS_DEP_TIME) 9.00 6.82    0.96    0.03 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# predictor plots
par(mfrow = c(2,2))
plot(gambc)
```



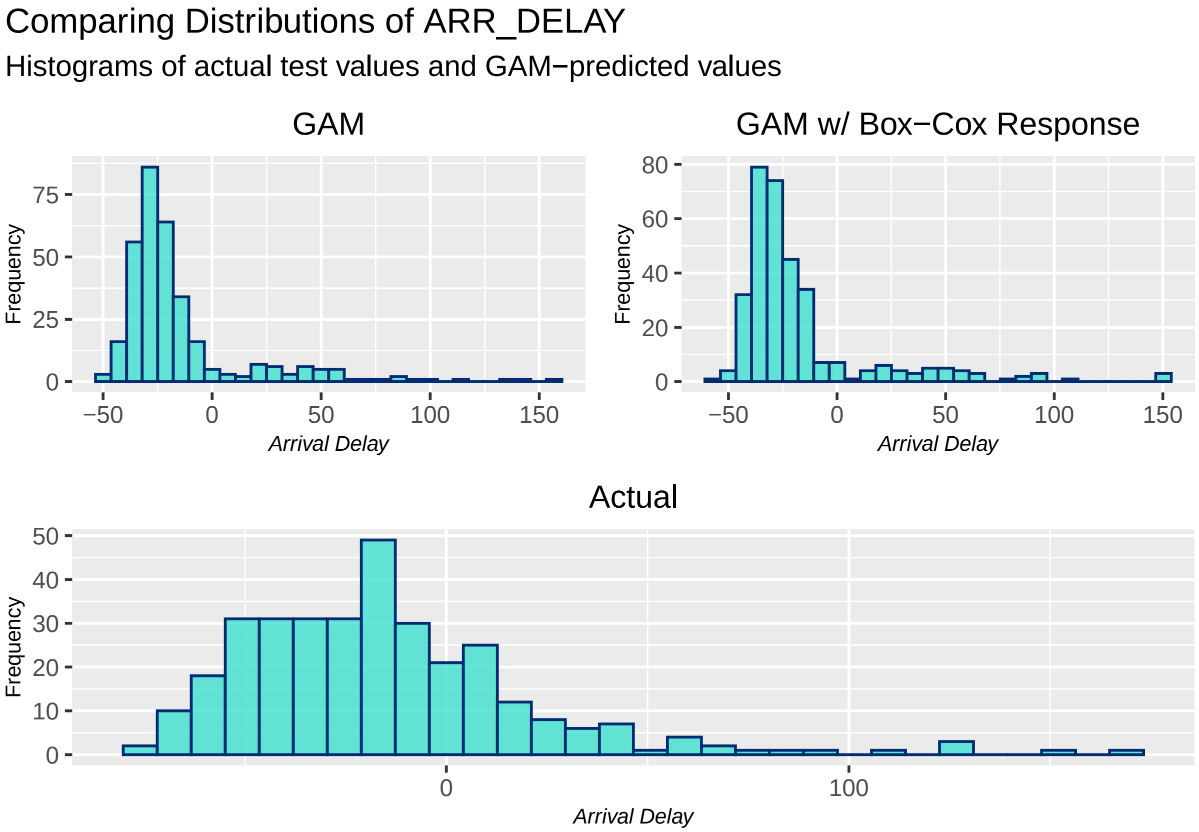
GAM Test Error Metrics & Predictions

```
# GAM predictions
## no BC
gam_preds <- predict.gam(gam02, newdata = test)
## BC
gambc_preds <- predict.gam(gambc, newdata = test)
adjgam_preds <- ((gambc_preds*(bc_lambda) + 1)^(1/bc_lambda))
bc_gam_pred = adjgam_preds - 77


## histogram of predictions vs. actual
# actual ARR_DELAY in test set
hist(test$ARR_DELAY)
```



```
ptest_actual <- ggplot(data = test, aes(x = ARR_DELAY)) +
  geom_histogram(fill = "#40E0D0", color = "#002D72", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "Actual") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# predicted ARR_DELAY in test set -- baseline lm
ptest_gam <- ggplot(data = test, aes(x = gam_preds)) +
  geom_histogram(fill = "#40E0D0", color = "#002D72", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "GAM") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# predicted ARR_DELAY in test set -- lm with log-trans
ptest_gam_bc <- ggplot(data = test, aes(x = bc_gam_pred)) +
  geom_histogram(fill = "#40E0D0", color = "#002D72", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "GAM w/ Box-Cox Response") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

gam_patchwork <- (ptest_gam + ptest_gam_bc) / ptest_actual
gam_patchwork + plot_annotation(
  title = 'Comparing Distributions of ARR_DELAY',
  subtitle = 'Histograms of actual test values and GAM-predicted values'
)
```

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



```
# test MSE calculations
gam_MSE <- sum((test$ARR_DELAY - gam_preds)^2, na.rm=T)/length(test$ARR_DELAY)
gam_MSE
```

```
## [1] 312.2953
```

```
gambc_MSE <- sum((test$ARR_DELAY - bc_gam_pred)^2, na.rm=T)/length(test$ARR_DELAY)
gambc_MSE
```

```
## [1] 317.4538
```

(3) Tree-Based Models

(a) Random Forests

By default, `randomForest()` uses $p/3$ variables when building a random forest of regression trees.

```r
set.seed(1)

# optimal number of predictors (param = mtry) used = 2 based on CV
rf.delay <- randomForest(ARR_DELAY ~ DAY_OF_MONTH +
                   TAXI_IN +
                   TAXI_OUT +
                   DEST +
                   DEP_DELAY +
                   CARRIER_DELAY +
                   NAS_DELAY,
                   data = train, na.action = na.omit, importance = TRUE,
                   ntree=10000, mtry=2)
```

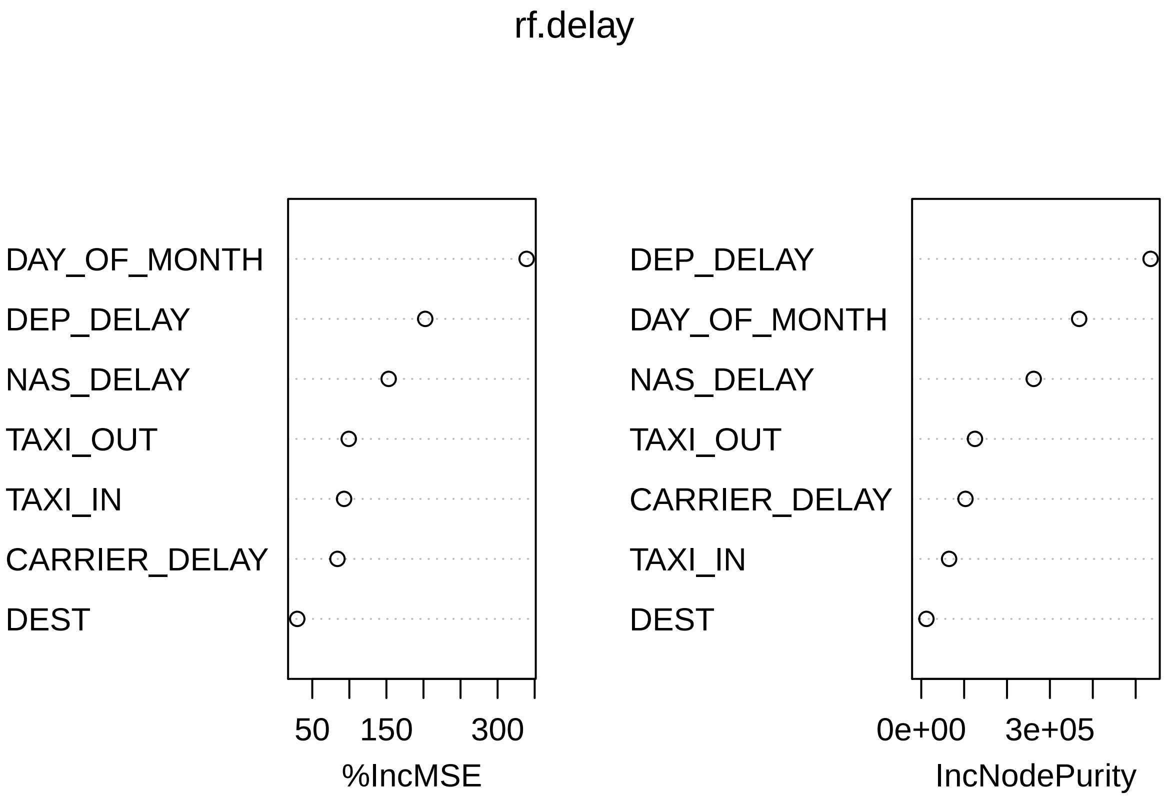
Using the `importance()` function, we can view the importance of each variable.

```r
importance(rf.delay)
```

```
##                  %IncMSE IncNodePurity
## DAY_OF_MONTH  339.08627     368261.46
## TAXI_IN        92.93643      64905.19
## TAXI_OUT       99.21626     125258.87
## DEST           29.76223      12009.51
## DEP_DELAY     202.38571     534776.35
## CARRIER_DELAY  83.95478     103105.51
## NAS_DELAY     153.05251     262232.63
```

Two measures of variable importance are reported. The former is based on the mean decrease in accuracy in predictions on the out of bag samples when a given variable is excluded from the model. The latter is a measure of the total decrease in node impurity that results from splits over that variable, averaged over all trees (this was plotted in Figure 8.9 in the text). In the case of regression trees, the node impurity is measured by the training RSS and for classification trees by the deviance. Plots of these importance measures can be produced using the `varImpPlot()` function.

```r
varImpPlot(rf.delay)
```



(b) Boosting

Here we use the `gbm()` package, and within it the `gbm()` function, to fit boosted regression trees to the `train` data set. We run `gbm()` with the option `distribution = "gaussian"` since this is a regression problem. The argument `n.trees = 150` indicates that we want 150 trees, and the option `interaction.depth = 3` limits the depth of each tree.

```
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1       1150.5648            -nan     0.1000  108.0894
##      2       1062.7120            -nan     0.1000   98.0251
##      3        999.8411            -nan     0.1000   54.3611
##      4        937.5774            -nan     0.1000   53.2725
##      5        877.3090            -nan     0.1000   60.5384
##      6        834.8623            -nan     0.1000   42.6809
##      7        782.6249            -nan     0.1000   41.6720
##      8        736.9349            -nan     0.1000   47.9831
##      9        695.5806            -nan     0.1000   40.5227
##     10        657.6592            -nan     0.1000   36.4710
##     20        421.6438            -nan     0.1000   15.4628
##     40        244.7935            -nan     0.1000    1.2456
##     60        184.0732            -nan     0.1000    1.4904
##     80        155.0727            -nan     0.1000    0.9043
##    100        140.8694            -nan     0.1000    0.3294
##    120        133.2812            -nan     0.1000    0.2873
##    140        127.0999            -nan     0.1000    0.1086
##    150        124.7120            -nan     0.1000   -1.0101
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1       1091.1076            -nan     0.1000  130.0192
##      2      961.6851            -nan     0.1000  157.4429
##      3      858.5946            -nan     0.1000  101.8085
##      4      790.1614            -nan     0.1000   64.1696
##      5      710.8182            -nan     0.1000   78.4191
##      6      649.3869            -nan     0.1000   63.5996
##      7      598.3666            -nan     0.1000   39.1273
##      8      545.5722            -nan     0.1000   54.2270
##      9      500.1991            -nan     0.1000   34.5864
##     10      467.1205            -nan     0.1000   34.3254
##     20      287.3160            -nan     0.1000    5.7970
##     40      166.8623            -nan     0.1000    3.5853
##     60      132.0353            -nan     0.1000    0.5102
##     80      118.0411            -nan     0.1000    0.0546
##    100      110.1089            -nan     0.1000    0.7461
##    120      103.2643            -nan     0.1000   -0.5363
##    140      100.1627            -nan     0.1000   -0.0438
##    150       98.7409            -nan     0.1000   -0.4050
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1066.5079            -nan     0.1000  173.6475
##      2      923.2312            -nan     0.1000  140.7612
##      3      801.1209            -nan     0.1000   93.9866
##      4      714.0700            -nan     0.1000   88.0321
##      5      640.2316            -nan     0.1000   68.1676
##      6      569.5613            -nan     0.1000   55.4898
##      7      505.9868            -nan     0.1000   58.5620
##      8      456.4054            -nan     0.1000   49.7937
##      9      419.3526            -nan     0.1000   27.1763
##     10      388.8173            -nan     0.1000   26.1372
##     20      233.6893            -nan     0.1000    7.8144
##     40      135.9065            -nan     0.1000    1.1181
##     60      110.4129            -nan     0.1000    0.0033
##     80      101.0143            -nan     0.1000   -1.0713
##    100       93.8919            -nan     0.1000    0.3906
##    120       90.0736            -nan     0.1000   -0.2786
##    140       86.1896            -nan     0.1000    0.0213
##    150       84.9967            -nan     0.1000   -0.3078
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1038.4961            -nan     0.1000   79.2910
##      2      964.6743            -nan     0.1000   63.7220
##      3      904.4326            -nan     0.1000   63.8304
##      4      846.0564            -nan     0.1000   35.8399
##      5      796.9160            -nan     0.1000   33.8357
##      6      741.3574            -nan     0.1000   53.0141
##      7      697.1677            -nan     0.1000   42.4855
##      8      658.3158            -nan     0.1000   31.6678
##      9      620.2354            -nan     0.1000   34.9740
##     10      583.9651            -nan     0.1000   37.1194
##     20      365.3850            -nan     0.1000   16.3536
##     40      211.8031            -nan     0.1000    3.8751
##     60      162.5473            -nan     0.1000    1.5584
##     80      139.3494            -nan     0.1000    0.7306
##    100      126.2946            -nan     0.1000    0.2218
##    120      117.2882            -nan     0.1000    0.1613
##    140      110.9744            -nan     0.1000    0.3039
##    150      108.7748            -nan     0.1000    0.2844
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1      977.1061            -nan     0.1000  113.4577
##      2      866.4147            -nan     0.1000  113.7672
##      3      768.6013            -nan     0.1000   79.1478
##      4      692.0857            -nan     0.1000   73.6998
##      5      626.7474            -nan     0.1000   64.8212
##      6      575.0267            -nan     0.1000   52.8815
##      7      521.4352            -nan     0.1000   40.5435
##      8      473.4024            -nan     0.1000   32.9714
##      9      435.6518            -nan     0.1000   33.5803
##     10      404.0142            -nan     0.1000   30.8877
##     20      237.3946            -nan     0.1000    9.0847
##     40      148.7742            -nan     0.1000    0.6326
##     60      116.9303            -nan     0.1000   -0.0815
##     80      103.5219            -nan     0.1000    0.3205
##    100       97.1446            -nan     0.1000    0.0267
##    120       93.7601            -nan     0.1000   -0.2853
##    140       90.1817            -nan     0.1000   -0.2491
##    150       88.4311            -nan     0.1000    0.0747
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1      979.2186            -nan     0.1000  157.4003
##      2      843.8291            -nan     0.1000  140.3897
##      3      728.9358            -nan     0.1000  107.9369
##      4      657.4075            -nan     0.1000   73.6883
##      5      583.9841            -nan     0.1000   74.7565
##      6      525.9856            -nan     0.1000   47.9538
##      7      471.0073            -nan     0.1000   45.7894
##      8      421.1825            -nan     0.1000   45.8401
##      9      381.2552            -nan     0.1000   28.7010
##     10      349.2513            -nan     0.1000   25.4642
##     20      197.4749            -nan     0.1000    7.5401
##     40      118.1161            -nan     0.1000    0.2761
##     60       96.2397            -nan     0.1000    0.0293
##     80       89.0182            -nan     0.1000    0.3721
##    100       83.6028            -nan     0.1000   -0.2090
##    120       79.7778            -nan     0.1000   -0.2337
##    140       76.0114            -nan     0.1000    0.0092
##    150       74.8119            -nan     0.1000   -0.2349
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1043.1800            -nan     0.1000   65.1818
##      2      959.4253            -nan     0.1000   70.1816
##      3      896.6926            -nan     0.1000   61.6784
##      4      843.1070            -nan     0.1000   50.6219
##      5      796.5353            -nan     0.1000   40.8339
##      6      746.4385            -nan     0.1000   46.4100
##      7      702.8579            -nan     0.1000   41.7416
##      8      663.6213            -nan     0.1000   38.0004
##      9      625.0179            -nan     0.1000   39.5442
##     10      591.8549            -nan     0.1000   27.8403
##     20      378.0878            -nan     0.1000   12.1186
##     40      231.7994            -nan     0.1000    3.0440
##     60      180.3416            -nan     0.1000    1.4298
##     80      156.3828            -nan     0.1000    0.6180
##    100      144.4843            -nan     0.1000    0.4221
##    120      136.6853            -nan     0.1000   -0.0499
##    140      130.7566            -nan     0.1000    0.0179
##    150      128.6565            -nan     0.1000   -0.3876
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1      988.9693            -nan     0.1000  135.6243
##      2      878.1054            -nan     0.1000  115.2549
##      3      782.7530            -nan     0.1000   68.8872
##      4      706.5929            -nan     0.1000   65.4505
##      5      647.2079            -nan     0.1000   53.1487
##      6      584.1888            -nan     0.1000   65.6355
##      7      536.8114            -nan     0.1000   43.1166
##      8      496.6526            -nan     0.1000   42.0299
##      9      460.4912            -nan     0.1000   35.7958
##     10      431.7768            -nan     0.1000   27.7186
##     20      263.1444            -nan     0.1000    9.9121
##     40      160.8285            -nan     0.1000    1.3644
##     60      131.1793            -nan     0.1000    0.8514
##     80      117.1487            -nan     0.1000    0.2811
##    100      109.9067            -nan     0.1000   -0.3520
##    120      103.3028            -nan     0.1000   -0.0456
##    140       99.4621            -nan     0.1000   -1.4216
##    150       97.8404            -nan     0.1000   -0.1779
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1      963.7173            -nan     0.1000  145.6485
##      2      830.0235            -nan     0.1000  140.3019
##      3      729.2431            -nan     0.1000  112.9741
##      4      642.8786            -nan     0.1000   85.5526
##      5      579.7839            -nan     0.1000   67.1794
##      6      525.0721            -nan     0.1000   54.9593
##      7      482.4734            -nan     0.1000   44.9557
##      8      440.6059            -nan     0.1000   36.2972
##      9      405.1308            -nan     0.1000   30.6701
##     10      377.1782            -nan     0.1000   32.2158
##     20      223.1937            -nan     0.1000    8.3633
##     40      137.5210            -nan     0.1000    2.7908
##     60      115.6683            -nan     0.1000   -0.1178
##     80      103.5987            -nan     0.1000    0.1486
##    100       97.4186            -nan     0.1000    0.0468
##    120       92.1760            -nan     0.1000   -0.6028
##    140       87.8751            -nan     0.1000   -0.0790
##    150       86.0851            -nan     0.1000   -0.2352
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1114.9069            -nan     0.1000  111.0734
##      2     1026.6882            -nan     0.1000   60.7724
##      3      960.8236            -nan     0.1000   65.4554
##      4      905.6734             -nan     0.1000   56.6590
##      5      844.7358             -nan     0.1000   56.0554
##      6      790.0563             -nan     0.1000   37.1147
##      7      747.9614             -nan     0.1000   43.9995
##      8      703.2455             -nan     0.1000   37.1534
##      9      660.5436             -nan     0.1000   37.6661
##     10      620.8812             -nan     0.1000   37.8569
##     20      394.0971             -nan     0.1000   13.1611
##     40      227.3770             -nan     0.1000    3.0090
##     60      175.9880             -nan     0.1000    0.6697
##     80      153.5385             -nan     0.1000    0.4214
##    100      141.7942             -nan     0.1000    0.0400
##    120      133.9781             -nan     0.1000    0.2538
##    140      128.5789             -nan     0.1000   -0.6216
##    150      127.0912             -nan     0.1000    0.2749
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1058.4375             -nan     0.1000  179.6786
##      2      934.4213             -nan     0.1000  123.0235
##      3      826.0630             -nan     0.1000  119.9622
##      4      741.0864             -nan     0.1000   76.9391
##      5      673.9855             -nan     0.1000   59.9329
##      6      614.3471             -nan     0.1000   63.7129
##      7      565.6583             -nan     0.1000   51.6028
##      8      515.4718             -nan     0.1000   48.5894
##      9      473.3732             -nan     0.1000   39.6733
##     10      437.3717             -nan     0.1000   25.2694
##     20      255.5560             -nan     0.1000    9.7985
##     40      158.6039             -nan     0.1000    0.8082
##     60      130.2847             -nan     0.1000    1.6124
##     80      119.4850             -nan     0.1000    0.1706
##    100      113.3957             -nan     0.1000   -0.4501
##    120      107.7894             -nan     0.1000    0.0992
##    140      103.8321             -nan     0.1000   -0.2636
##    150      102.7621             -nan     0.1000   -0.2770
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1050.1920             -nan     0.1000  157.4568
##      2      908.9149             -nan     0.1000  134.2770
##      3      813.2572             -nan     0.1000   88.2433
##      4      713.7046             -nan     0.1000   97.3873
##      5      630.2140             -nan     0.1000   73.9902
##      6      555.7110             -nan     0.1000   72.0744
##      7      505.4664             -nan     0.1000   57.3740
##      8      459.7692             -nan     0.1000   50.6590
##      9      418.2648             -nan     0.1000   38.7313
##     10      381.5394             -nan     0.1000   28.0108
##     20      218.5273             -nan     0.1000    8.5399
##     40      139.6013             -nan     0.1000    1.0679
##     60      115.4817             -nan     0.1000    0.4317
##     80      105.5851             -nan     0.1000   -0.4976
##    100       98.7866             -nan     0.1000   -0.0657
##    120       94.8003             -nan     0.1000   -0.2332
##    140       92.0789             -nan     0.1000   -0.4928
##    150       89.9621            -nan     0.1000   -0.4581
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1363.0377            -nan     0.1000  115.9742
##      2     1261.0838            -nan     0.1000   95.4869
##      3     1169.9134            -nan     0.1000   89.4782
##      4     1098.3658            -nan     0.1000   58.2659
##      5     1033.3767            -nan     0.1000   65.9647
##      6      975.8048            -nan     0.1000   57.3396
##      7      916.9678            -nan     0.1000   51.0980
##      8      866.2389            -nan     0.1000   48.7142
##      9      822.0977            -nan     0.1000   45.7419
##     10      780.3579            -nan     0.1000   40.0106
##     20      473.4706            -nan     0.1000   21.2260
##     40      261.5182            -nan     0.1000    4.9859
##     60      188.8009            -nan     0.1000    2.0729
##     80      156.3942            -nan     0.1000    0.2772
##    100      139.4622            -nan     0.1000    0.4014
##    120      130.4820            -nan     0.1000    0.2730
##    140      123.5861            -nan     0.1000   -0.1129
##    150      120.8073            -nan     0.1000    0.0414
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1313.9267            -nan     0.1000  178.6950
##      2     1154.3750            -nan     0.1000  158.1254
##      3     1021.4058            -nan     0.1000   96.9070
##      4      907.3896            -nan     0.1000   93.8171
##      5      821.2174            -nan     0.1000   79.4315
##      6      735.9728            -nan     0.1000   65.2562
##      7      672.5909            -nan     0.1000   59.5681
##      8      625.1451            -nan     0.1000   44.8287
##      9      569.7428            -nan     0.1000   37.7258
##     10      521.7478            -nan     0.1000   38.0977
##     20      296.2888            -nan     0.1000   12.0787
##     40      167.2275            -nan     0.1000    1.9542
##     60      133.7161            -nan     0.1000    0.8959
##     80      115.3132            -nan     0.1000   -0.3287
##    100      107.6759            -nan     0.1000    0.3238
##    120      102.2019            -nan     0.1000   -0.2904
##    140       96.2270            -nan     0.1000    0.0778
##    150       94.6262            -nan     0.1000   -0.3259
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1284.6787            -nan     0.1000  216.3611
##      2     1110.8225            -nan     0.1000  156.8866
##      3      957.2629            -nan     0.1000  157.3410
##      4      837.9827            -nan     0.1000  107.2450
##      5      739.2871            -nan     0.1000   94.1477
##      6      657.4487            -nan     0.1000   70.9209
##      7      592.1601            -nan     0.1000   65.7733
##      8      533.5499            -nan     0.1000   54.9894
##      9      481.1973            -nan     0.1000   54.6397
##     10      450.3253            -nan     0.1000   32.3668
##     20      242.1455            -nan     0.1000   16.5360
##     40      134.1906             -nan     0.1000    1.2931
##     60      107.5346             -nan     0.1000    0.6984
##     80       96.4049             -nan     0.1000    0.4291
##    100       88.7862             -nan     0.1000    0.3195
##    120       84.0447             -nan     0.1000   -0.3354
##    140       79.9662             -nan     0.1000   -0.0714
##    150       78.3658             -nan     0.1000   -0.0550
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1119.6872             -nan     0.1000   64.0268
##      2     1028.6291             -nan     0.1000   89.2680
##      3      955.2203             -nan     0.1000   51.7304
##      4      886.0096             -nan     0.1000   76.9672
##      5      833.6934             -nan     0.1000   52.1605
##      6      792.9316             -nan     0.1000   36.7743
##      7      744.9836             -nan     0.1000   38.6176
##      8      697.4934             -nan     0.1000   37.4781
##      9      656.1072             -nan     0.1000   39.4088
##     10      622.1726             -nan     0.1000   33.2767
##     20      396.7593             -nan     0.1000   17.3952
##     40      235.1882             -nan     0.1000    1.0045
##     60      179.7141             -nan     0.1000    1.2229
##     80      154.9271             -nan     0.1000    0.6423
##    100      143.1362             -nan     0.1000    0.2508
##    120      135.1987             -nan     0.1000    0.0048
##    140      129.8053             -nan     0.1000   -0.5869
##    150      127.0031             -nan     0.1000    0.1124
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1030.7566             -nan     0.1000  138.8045
##      2      931.4097             -nan     0.1000  108.5589
##      3      823.2101             -nan     0.1000  119.9196
##      4      737.1424             -nan     0.1000   83.8840
##      5      682.1829             -nan     0.1000   52.8919
##      6      617.9732             -nan     0.1000   55.2543
##      7      564.1432             -nan     0.1000   44.3180
##      8      518.3703             -nan     0.1000   41.4856
##      9      485.0086             -nan     0.1000   35.0296
##     10      459.1011             -nan     0.1000   24.7205
##     20      265.7766             -nan     0.1000    6.5308
##     40      163.6818             -nan     0.1000    1.6940
##     60      134.7479             -nan     0.1000    0.6209
##     80      121.5619             -nan     0.1000    0.4184
##    100      111.6734             -nan     0.1000   -0.3092
##    120      106.5058             -nan     0.1000   -0.0169
##    140      101.4909             -nan     0.1000    0.1760
##    150       98.6352             -nan     0.1000    0.0204
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1030.4886             -nan     0.1000  169.4195
##      2      894.3337             -nan     0.1000  147.4280
##      3      781.2207             -nan     0.1000   99.2478
##      4      692.5225             -nan     0.1000   86.5989
##      5      614.2082             -nan     0.1000   74.9347
##      6      556.0481            -nan     0.1000   53.3782
##      7      506.4840            -nan     0.1000   45.6967
##      8      456.4495            -nan     0.1000   44.0783
##      9      425.2643            -nan     0.1000   34.2144
##     10      394.9264            -nan     0.1000   30.4285
##     20      233.0086            -nan     0.1000    7.0539
##     40      142.0020            -nan     0.1000    1.1186
##     60      116.1049            -nan     0.1000    0.5247
##     80      102.4701            -nan     0.1000   -0.5115
##    100       94.1522            -nan     0.1000    0.1074
##    120       88.0607            -nan     0.1000    0.2569
##    140       84.4240            -nan     0.1000    0.1709
##    150       82.9162            -nan     0.1000   -0.0851
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1151.1140            -nan     0.1000   74.8637
##      2     1073.9338            -nan     0.1000   73.2535
##      3     1014.7446            -nan     0.1000   60.9543
##      4      947.6675            -nan     0.1000   59.7251
##      5      902.7024            -nan     0.1000   48.6272
##      6      840.8978            -nan     0.1000   61.2264
##      7      795.5811            -nan     0.1000   39.0083
##      8      748.1772            -nan     0.1000   48.2803
##      9      709.2787            -nan     0.1000   36.1646
##     10      675.0291            -nan     0.1000   35.6680
##     20      425.3133            -nan     0.1000   16.5287
##     40      244.8662            -nan     0.1000    1.7448
##     60      187.7142            -nan     0.1000    1.3188
##     80      158.9160            -nan     0.1000    0.8889
##    100      145.4590            -nan     0.1000    0.4266
##    120      136.4194            -nan     0.1000    0.2414
##    140      130.0089            -nan     0.1000    0.3067
##    150      128.3017            -nan     0.1000   -1.5994
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1089.0163            -nan     0.1000  147.1273
##      2      969.9221            -nan     0.1000  116.2787
##      3      880.5462            -nan     0.1000   78.6197
##      4      812.5230            -nan     0.1000   59.9873
##      5      726.9211            -nan     0.1000   84.5285
##      6      677.4496            -nan     0.1000   52.2021
##      7      612.9353            -nan     0.1000   50.6274
##      8      561.4688            -nan     0.1000   48.4978
##      9      512.3283            -nan     0.1000   45.8716
##     10      483.8197            -nan     0.1000   29.7787
##     20      277.0257            -nan     0.1000   10.2003
##     40      170.0154            -nan     0.1000    0.9824
##     60      138.0782            -nan     0.1000    0.1468
##     80      121.8979            -nan     0.1000    1.0083
##    100      113.0314            -nan     0.1000    0.7136
##    120      106.1635            -nan     0.1000    0.4506
##    140      101.5379            -nan     0.1000   -0.1965
##    150       99.3361            -nan     0.1000    0.0973
##
```

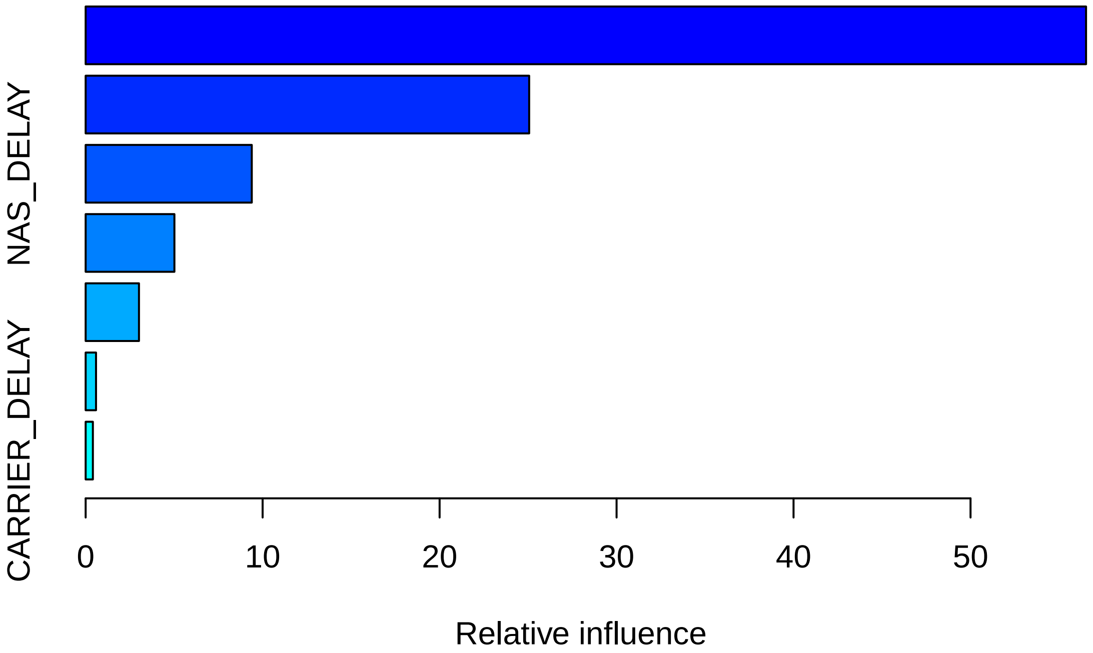
```
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1076.3660            -nan     0.1000  166.0326
##      2      934.8358            -nan     0.1000  127.5496
##      3      821.5449            -nan     0.1000  106.6992
##      4      746.0042            -nan     0.1000   77.6186
##      5      662.0705            -nan     0.1000   88.5528
##      6      587.9474            -nan     0.1000   68.8832
##      7      524.7118            -nan     0.1000   57.8505
##      8      479.7467            -nan     0.1000   47.0668
##      9      436.0507            -nan     0.1000   39.3705
##     10      399.8243            -nan     0.1000   31.9315
##     20      220.4503            -nan     0.1000    6.6917
##     40      137.8457            -nan     0.1000    0.0340
##     60      111.5257            -nan     0.1000    0.4765
##     80      103.2541            -nan     0.1000    0.3290
##    100       95.8835            -nan     0.1000    0.0615
##    120       90.3473            -nan     0.1000   -1.0049
##    140       86.4337            -nan     0.1000   -0.4626
##    150       84.6927            -nan     0.1000   -0.2075
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1339.4377            -nan     0.1000  113.2613
##      2     1216.2615            -nan     0.1000   99.2026
##      3     1126.4295            -nan     0.1000   68.4633
##      4     1046.2734            -nan     0.1000   82.6301
##      5      983.9641            -nan     0.1000   62.1021
##      6      914.1832            -nan     0.1000   58.4017
##      7      852.3048            -nan     0.1000   55.8210
##      8      808.5896            -nan     0.1000   38.0359
##      9      761.6549            -nan     0.1000   46.5411
##     10      717.0981            -nan     0.1000   45.1370
##     20      436.3161            -nan     0.1000    5.0169
##     40      247.8442            -nan     0.1000    4.0908
##     60      189.6155            -nan     0.1000    1.2188
##     80      163.7345            -nan     0.1000   -0.4299
##    100      151.1381            -nan     0.1000    0.3984
##    120      143.2722            -nan     0.1000    0.3737
##    140      137.0679            -nan     0.1000    0.2390
##    150      134.8423            -nan     0.1000   -0.2984
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1293.9024            -nan     0.1000  152.8322
##      2     1141.1291            -nan     0.1000  163.8377
##      3     1004.9357            -nan     0.1000  125.6723
##      4      904.6677            -nan     0.1000  101.5808
##      5      806.7888            -nan     0.1000   95.9764
##      6      727.2010            -nan     0.1000   56.4767
##      7      671.4384            -nan     0.1000   51.6276
##      8      611.6293            -nan     0.1000   47.2025
##      9      561.1445            -nan     0.1000   48.9747
##     10      523.9407            -nan     0.1000   41.5284
##     20      290.1424            -nan     0.1000    8.3678
##     40      169.4780            -nan     0.1000    2.2472
##     60      139.4834            -nan     0.1000    0.5103
##     80      124.4535            -nan     0.1000    0.4551
##    100      116.3915            -nan     0.1000    0.0335
##    120      109.1921            -nan     0.1000   -0.3405
##    140      105.2343            -nan     0.1000   -0.4163
##    150      103.8512            -nan     0.1000   -0.3317
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1267.3354            -nan     0.1000  185.0019
##      2     1107.6952            -nan     0.1000  184.8420
##      3      963.0019            -nan     0.1000  143.9640
##      4      842.8009            -nan     0.1000  109.3526
##      5      751.5434            -nan     0.1000  106.4052
##      6      668.2674            -nan     0.1000   99.3912
##      7      596.6896            -nan     0.1000   53.4083
##      8      542.7084            -nan     0.1000   57.2947
##      9      501.0338            -nan     0.1000   42.9532
##     10      455.1269            -nan     0.1000   46.6512
##     20      255.6455            -nan     0.1000    8.0047
##     40      152.1644            -nan     0.1000    0.5435
##     60      122.5953            -nan     0.1000    0.5605
##     80      109.4411            -nan     0.1000    0.0806
##    100      102.2738            -nan     0.1000    0.0991
##    120       96.9834            -nan     0.1000   -0.6580
##    140       92.7473            -nan     0.1000   -0.6350
##    150       90.8796            -nan     0.1000   -0.2192
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1309.6891            -nan     0.1000  119.7429
##      2     1192.8718            -nan     0.1000  131.6083
##      3     1106.9567            -nan     0.1000   79.0799
##      4     1030.6708            -nan     0.1000   83.9500
##      5      960.5429            -nan     0.1000   60.8600
##      6      892.6716            -nan     0.1000   56.2380
##      7      833.7406            -nan     0.1000   62.1241
##      8      785.0503            -nan     0.1000   50.2280
##      9      731.9059            -nan     0.1000   58.2727
##     10      686.1060            -nan     0.1000   47.9452
##     20      400.7869            -nan     0.1000   13.7796
##     40      224.7410            -nan     0.1000    2.2285
##     60      170.6971            -nan     0.1000    1.0392
##     80      145.5117            -nan     0.1000    0.8516
##    100      132.2849            -nan     0.1000    0.1497
##    120      123.5844            -nan     0.1000   -0.1524
##    140      117.6299            -nan     0.1000    0.0698
##    150      115.2245            -nan     0.1000   -0.0096
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1215.0085            -nan     0.1000  178.3146
##      2     1083.5683            -nan     0.1000  136.7143
##      3      980.2517            -nan     0.1000  107.0384
##      4      875.5395            -nan     0.1000   91.5845
##      5      777.3021            -nan     0.1000   89.5319
##      6      697.5710            -nan     0.1000   81.7018
##      7      629.7203            -nan     0.1000   48.0097
##      8      574.1415            -nan     0.1000   61.9125
##      9      524.1105            -nan     0.1000   43.0415
##     10      487.4983            -nan     0.1000   38.4445
##     20      262.9601            -nan     0.1000    5.6366
##     40      159.6440            -nan     0.1000    1.8309
##     60      129.1143            -nan     0.1000    0.1300
##     80      114.9550            -nan     0.1000    0.0602
##    100      106.5549            -nan     0.1000    0.1337
##    120      101.1085            -nan     0.1000   -0.0446
##    140       96.6816            -nan     0.1000   -0.2191
##    150       94.8257            -nan     0.1000   -0.4427
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1202.8157            -nan     0.1000  211.6199
##      2     1043.5734            -nan     0.1000  158.7406
##      3      894.0216            -nan     0.1000  117.4613
##      4      778.1679            -nan     0.1000  113.2346
##      5      696.3307            -nan     0.1000   97.7456
##      6      617.0662            -nan     0.1000   76.7895
##      7      548.1352            -nan     0.1000   55.9634
##      8      497.3939            -nan     0.1000   48.5479
##      9      452.4059            -nan     0.1000   43.9317
##     10      409.5711            -nan     0.1000   38.9295
##     20      226.4281            -nan     0.1000    9.2007
##     40      131.8420            -nan     0.1000    1.4361
##     60      107.8706            -nan     0.1000    0.4472
##     80       97.8616            -nan     0.1000    0.1277
##    100       90.9571            -nan     0.1000   -0.1795
##    120       86.1733            -nan     0.1000   -0.4309
##    140       81.2866            -nan     0.1000   -0.3627
##    150       79.7317            -nan     0.1000   -0.1314
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1197.8704            -nan     0.1000  105.9670
##      2     1116.4273            -nan     0.1000   79.7892
##      3     1039.6990            -nan     0.1000   79.0002
##      4      967.4720            -nan     0.1000   69.3039
##      5      914.7650            -nan     0.1000   54.4291
##      6      861.5939            -nan     0.1000   60.7256
##      7      806.6787            -nan     0.1000   52.6622
##      8      764.8375            -nan     0.1000   42.8954
##      9      732.0972            -nan     0.1000   34.8340
##     10      682.1197            -nan     0.1000   22.3085
##     20      422.4240            -nan     0.1000   15.8138
##     40      244.9176            -nan     0.1000    2.6851
##     60      186.9602            -nan     0.1000    1.5573
##     80      160.2296            -nan     0.1000    0.5846
##    100      147.3465            -nan     0.1000   -0.0290
##    120      140.7966            -nan     0.1000   -0.7363
##    140      135.9467            -nan     0.1000    0.0404
##    150      133.1098            -nan     0.1000    0.0520
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1138.3148            -nan     0.1000  161.1864
##      2     1003.7702            -nan     0.1000  111.5627
##      3      885.9315            -nan     0.1000   88.6904
##      4      787.9267            -nan     0.1000   80.9427
##      5      718.3539            -nan     0.1000   73.0769
##      6      654.9425            -nan     0.1000   66.9388
##      7      593.8499            -nan     0.1000   57.3728
##      8      552.5312            -nan     0.1000   42.2236
##      9      506.1835            -nan     0.1000   32.1548
##     10      470.7422            -nan     0.1000   20.3838
##     20      280.8118            -nan     0.1000   10.4112
##     40      168.5224            -nan     0.1000    1.9261
##     60      138.6952            -nan     0.1000    0.5653
##     80      125.8292            -nan     0.1000    0.5666
##    100      116.6583            -nan     0.1000   -0.0397
##    120      110.5151            -nan     0.1000   -0.0843
##    140      104.5755            -nan     0.1000   -0.5364
##    150      102.4542            -nan     0.1000   -0.0456
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1122.9821            -nan     0.1000  178.7064
##      2      977.8391            -nan     0.1000  140.7097
##      3      857.8848            -nan     0.1000  101.6812
##      4      750.4677            -nan     0.1000   97.1855
##      5      662.0855            -nan     0.1000   56.7001
##      6      585.8205            -nan     0.1000   66.1089
##      7      536.4547            -nan     0.1000   49.5552
##      8      486.1739            -nan     0.1000   47.3448
##      9      446.9455            -nan     0.1000   40.6060
##     10      411.8919            -nan     0.1000   34.5107
##     20      234.3615            -nan     0.1000    8.2405
##     40      140.8457            -nan     0.1000    0.6081
##     60      115.9656            -nan     0.1000   -0.3337
##     80      105.0992            -nan     0.1000   -0.0829
##    100       99.1904            -nan     0.1000   -0.3598
##    120       93.7467            -nan     0.1000   -0.6929
##    140       89.7672            -nan     0.1000   -0.1951
##    150       88.6174            -nan     0.1000   -0.6462
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1023.4582            -nan     0.1000   68.3441
##      2      967.9584            -nan     0.1000   59.5204
##      3      909.0685            -nan     0.1000   63.8819
##      4      854.1288            -nan     0.1000   43.4207
##      5      810.2001            -nan     0.1000   44.7913
##      6      765.1487            -nan     0.1000   46.8162
##      7      725.9762            -nan     0.1000   37.0026
##      8      675.6022            -nan     0.1000   31.4953
##      9      644.0094            -nan     0.1000   28.9816
##     10      616.3479            -nan     0.1000   29.9801
##     20      393.2961            -nan     0.1000    8.9774
##     40      235.7948            -nan     0.1000    3.5970
##     60      179.8041            -nan     0.1000    1.5017
##     80      150.9343            -nan     0.1000    0.7221
##    100      136.3889            -nan     0.1000   -1.4436
##    120      129.0320             -nan     0.1000    0.1599
##    140      123.3141             -nan     0.1000    0.2362
##    150      121.3434             -nan     0.1000   -0.7116
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1      982.6173             -nan     0.1000  147.4154
##      2      873.1261             -nan     0.1000   93.7166
##      3      780.8316             -nan     0.1000   83.4734
##      4      705.9900             -nan     0.1000   79.7419
##      5      650.7736             -nan     0.1000   59.2770
##      6      603.7625             -nan     0.1000   46.4562
##      7      557.2159             -nan     0.1000   44.0364
##      8      507.2621             -nan     0.1000   38.9514
##      9      458.6382             -nan     0.1000   36.5356
##     10      425.9856             -nan     0.1000   32.0136
##     20      268.7626             -nan     0.1000   10.8314
##     40      163.7822             -nan     0.1000    1.5170
##     60      129.1078             -nan     0.1000   -0.2815
##     80      115.6694             -nan     0.1000   -0.5982
##    100      108.3858             -nan     0.1000    0.0414
##    120      102.1804             -nan     0.1000    0.2199
##    140       97.5815             -nan     0.1000   -1.0489
##    150       95.6573             -nan     0.1000   -0.4461
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1      960.5786             -nan     0.1000  154.4063
##      2      843.3030             -nan     0.1000  117.0651
##      3      741.9885             -nan     0.1000  110.7751
##      4      647.6381             -nan     0.1000   82.1691
##      5      577.1404             -nan     0.1000   57.7678
##      6      518.5489             -nan     0.1000   49.1300
##      7      471.1645             -nan     0.1000   41.3249
##      8      436.8741             -nan     0.1000   25.9718
##      9      404.6363             -nan     0.1000   25.0365
##     10      374.0788             -nan     0.1000   25.2631
##     20      221.2741             -nan     0.1000    8.9664
##     40      130.5958             -nan     0.1000    1.2295
##     60      104.8111             -nan     0.1000   -0.9402
##     80       96.0620             -nan     0.1000   -0.1090
##    100       89.7521             -nan     0.1000   -0.1655
##    120       85.2111             -nan     0.1000   -0.5734
##    140       81.8484             -nan     0.1000   -0.4011
##    150       79.9122             -nan     0.1000    0.0527
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1173.3057             -nan     0.1000   53.0337
##      2     1104.1929             -nan     0.1000   75.5040
##      3     1034.8149             -nan     0.1000   73.8075
##      4      976.3153             -nan     0.1000   57.9518
##      5      916.5336             -nan     0.1000   55.0927
##      6      871.8483             -nan     0.1000   46.3780
##      7      820.0678             -nan     0.1000   41.5526
##      8      777.0558             -nan     0.1000   52.3215
##      9      733.4139             -nan     0.1000   29.6760
##     10      698.0279            -nan     0.1000   33.0200
##     20      441.0445            -nan     0.1000   16.1338
##     40      264.6720            -nan     0.1000    2.5522
##     60      199.0969            -nan     0.1000    1.4790
##     80      170.6772            -nan     0.1000    0.8804
##    100      156.7461            -nan     0.1000    0.2365
##    120      148.7043            -nan     0.1000   -0.8564
##    140      142.8518            -nan     0.1000    0.1958
##    150      140.7197            -nan     0.1000   -0.0893
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1172.7678            -nan     0.1000  100.4373
##      2     1038.9700            -nan     0.1000  143.6029
##      3      956.5260            -nan     0.1000   68.2986
##      4      860.1925            -nan     0.1000   92.9443
##      5      776.9312            -nan     0.1000   62.7130
##      6      701.8254            -nan     0.1000   71.9763
##      7      639.9996            -nan     0.1000   59.3219
##      8      586.9620            -nan     0.1000   39.7598
##      9      540.6001            -nan     0.1000   41.4294
##     10      509.9882            -nan     0.1000   31.6544
##     20      310.5632            -nan     0.1000   11.7259
##     40      187.8151            -nan     0.1000    2.0228
##     60      150.1506            -nan     0.1000   -0.0571
##     80      133.2271            -nan     0.1000    0.3945
##    100      122.1332            -nan     0.1000    0.6666
##    120      117.1130            -nan     0.1000   -0.1163
##    140      112.4926            -nan     0.1000   -0.3512
##    150      111.4169            -nan     0.1000   -0.2453
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1098.0963            -nan     0.1000  136.6717
##      2     1001.6572            -nan     0.1000  110.3699
##      3      876.4455            -nan     0.1000  116.3827
##      4      768.7673            -nan     0.1000   89.0480
##      5      694.6607            -nan     0.1000   69.1399
##      6      628.2615            -nan     0.1000   65.2577
##      7      566.9362            -nan     0.1000   58.2404
##      8      523.7986            -nan     0.1000   44.3024
##      9      476.6739            -nan     0.1000   34.2358
##     10      441.0850            -nan     0.1000   36.1024
##     20      252.1497            -nan     0.1000    9.0238
##     40      151.3068            -nan     0.1000    1.0013
##     60      126.2079            -nan     0.1000    0.3360
##     80      115.3667            -nan     0.1000   -0.8247
##    100      106.5691            -nan     0.1000    0.0017
##    120      101.4904            -nan     0.1000    0.1990
##    140       97.1520            -nan     0.1000   -0.1910
##    150       95.2360            -nan     0.1000   -0.2821
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1201.4410            -nan     0.1000  106.1190
##      2     1112.0699            -nan     0.1000   89.6509
##      3     1043.7033            -nan     0.1000   68.3250
##      4      987.0400            -nan     0.1000   55.9010
##      5      924.1874            -nan     0.1000   53.4938
##      6      877.9404            -nan     0.1000   48.3207
##      7      823.8676            -nan     0.1000   46.5479
##      8      773.5133            -nan     0.1000   50.9513
##      9      726.6435            -nan     0.1000   41.1811
##     10      687.2881            -nan     0.1000   32.1867
##     20      428.2893            -nan     0.1000   16.4960
##     40      247.9174            -nan     0.1000    3.8608
##     60      183.2643            -nan     0.1000    1.8177
##     80      153.9239            -nan     0.1000    0.7093
##    100      139.5839            -nan     0.1000   -0.0992
##    120      130.6775            -nan     0.1000   -0.0728
##    140      124.8761            -nan     0.1000   -0.5797
##    150      122.2978            -nan     0.1000    0.0473
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1142.7927            -nan     0.1000  151.0889
##      2     1014.7561            -nan     0.1000  124.4026
##      3      908.0770            -nan     0.1000   88.4686
##      4      812.2367            -nan     0.1000   92.8222
##      5      754.5227            -nan     0.1000   55.9591
##      6      686.4518            -nan     0.1000   64.5867
##      7      626.9016            -nan     0.1000   60.8306
##      8      568.7257            -nan     0.1000   39.6262
##      9      533.7047            -nan     0.1000   38.9119
##     10      490.3844            -nan     0.1000   25.6961
##     20      280.8341            -nan     0.1000   11.5409
##     40      162.4504            -nan     0.1000    2.3763
##     60      125.9654            -nan     0.1000   -0.4606
##     80      113.8271            -nan     0.1000    0.2730
##    100      107.0324            -nan     0.1000   -0.2279
##    120      100.7149            -nan     0.1000   -0.0411
##    140       97.1166            -nan     0.1000   -0.1578
##    150       95.0111            -nan     0.1000   -0.1561
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1156.1045            -nan     0.1000  168.0392
##      2      991.6610            -nan     0.1000  178.6425
##      3      873.8349            -nan     0.1000  122.0701
##      4      775.5410            -nan     0.1000   89.8189
##      5      685.0005            -nan     0.1000   82.8261
##      6      624.5754            -nan     0.1000   57.5314
##      7      558.5024            -nan     0.1000   43.5408
##      8      503.7201            -nan     0.1000   45.5906
##      9      461.8048            -nan     0.1000   49.5252
##     10      429.3099            -nan     0.1000   32.1101
##     20      226.6858            -nan     0.1000   10.5130
##     40      129.7483            -nan     0.1000    1.1179
##     60      106.9612            -nan     0.1000    0.1356
##     80       96.7065            -nan     0.1000    0.0488
##    100       91.2641            -nan     0.1000    0.0641
##    120       87.7454            -nan     0.1000   -0.2613
##    140       84.6140            -nan     0.1000    0.0046
##    150       83.3537            -nan     0.1000   -0.1391
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1035.7901            -nan     0.1000   58.7296
##      2      965.8432            -nan     0.1000   50.9052
##      3      906.2053            -nan     0.1000   65.9404
##      4      842.6515            -nan     0.1000   62.7205
##      5      795.6941            -nan     0.1000   43.9271
##      6      751.0854            -nan     0.1000   44.0143
##      7      705.3684            -nan     0.1000   43.3203
##      8      662.9367            -nan     0.1000   29.9252
##      9      628.5286            -nan     0.1000   23.8324
##     10      591.7874            -nan     0.1000   36.1055
##     20      380.0726            -nan     0.1000   13.3722
##     40      215.3355            -nan     0.1000    3.7943
##     60      164.8433            -nan     0.1000    1.1424
##     80      140.1305            -nan     0.1000    0.1823
##    100      127.3285            -nan     0.1000    0.3753
##    120      118.5926            -nan     0.1000    0.1254
##    140      112.7833            -nan     0.1000    0.2753
##    150      110.4796            -nan     0.1000    0.1521
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1      984.4417            -nan     0.1000  104.8746
##      2      876.2773            -nan     0.1000  106.6737
##      3      801.2080            -nan     0.1000   77.5352
##      4      712.2964            -nan     0.1000   79.4696
##      5      643.4845            -nan     0.1000   42.7919
##      6      579.3777            -nan     0.1000   58.4736
##      7      525.9397            -nan     0.1000   40.6531
##      8      478.4460            -nan     0.1000   44.2109
##      9      448.4120            -nan     0.1000   31.1903
##     10      418.4793            -nan     0.1000   30.5114
##     20      248.7991            -nan     0.1000    6.4246
##     40      150.1354            -nan     0.1000    0.9824
##     60      119.8076            -nan     0.1000    0.0967
##     80      107.4000            -nan     0.1000   -0.7326
##    100       99.6906            -nan     0.1000   -0.2750
##    120       94.1053            -nan     0.1000    0.2156
##    140       91.0177            -nan     0.1000   -0.1580
##    150       89.8213            -nan     0.1000    0.1896
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1      951.9572            -nan     0.1000  128.8859
##      2      842.2726            -nan     0.1000  117.5267
##      3      744.2457            -nan     0.1000   88.7939
##      4      659.7421            -nan     0.1000   79.6048
##      5      595.3616            -nan     0.1000   65.9342
##      6      547.8268            -nan     0.1000   49.5625
##      7      501.8491            -nan     0.1000   45.1066
##      8      453.5627            -nan     0.1000   53.1859
##      9      408.1017            -nan     0.1000   38.3713
##     10      376.2601            -nan     0.1000   26.7730
##     20      209.4982            -nan     0.1000    8.3822
##     40      123.2374             -nan     0.1000    2.6032
##     60       97.5851             -nan     0.1000    0.9637
##     80       87.1513             -nan     0.1000    0.1307
##    100       80.4227             -nan     0.1000   -0.0476
##    120       75.7581             -nan     0.1000   -0.0517
##    140       72.9355             -nan     0.1000   -0.2326
##    150       71.9447             -nan     0.1000   -0.1492
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1201.6287             -nan     0.1000   90.9115
##      2     1119.7142             -nan     0.1000   83.7937
##      3     1040.6954             -nan     0.1000   87.8484
##      4      985.5103             -nan     0.1000   58.0410
##      5      923.7542             -nan     0.1000   56.8231
##      6      870.1986             -nan     0.1000   47.7431
##      7      813.9796             -nan     0.1000   59.0307
##      8      771.3084             -nan     0.1000   45.1861
##      9      734.6957             -nan     0.1000   38.0202
##     10      691.2948             -nan     0.1000   45.7223
##     20      426.1964             -nan     0.1000   16.5375
##     40      247.8649             -nan     0.1000    3.8290
##     60      185.7757             -nan     0.1000    1.6255
##     80      156.0575             -nan     0.1000    0.7319
##    100      142.2254             -nan     0.1000   -0.8207
##    120      134.5285             -nan     0.1000    0.2423
##    140      128.5601             -nan     0.1000    0.1166
##    150      126.1168             -nan     0.1000    0.2170
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1157.7912             -nan     0.1000  143.5886
##      2     1022.0738             -nan     0.1000  138.6245
##      3      905.0947             -nan     0.1000   97.2034
##      4      809.8742             -nan     0.1000   90.6408
##      5      728.5079             -nan     0.1000   73.5228
##      6      655.3187             -nan     0.1000   60.1245
##      7      604.2588             -nan     0.1000   35.3958
##      8      556.4355             -nan     0.1000   45.5072
##      9      511.7440             -nan     0.1000   45.0474
##     10      476.4448             -nan     0.1000   27.4272
##     20      272.3418             -nan     0.1000   10.5469
##     40      165.1427             -nan     0.1000    3.5678
##     60      133.0993             -nan     0.1000   -0.6801
##     80      121.5918             -nan     0.1000   -0.0320
##    100      114.5075             -nan     0.1000    0.0147
##    120      109.9636             -nan     0.1000   -0.1104
##    140      104.0401             -nan     0.1000    0.0509
##    150      102.6555             -nan     0.1000    0.0085
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1133.5197             -nan     0.1000  172.7048
##      2      987.1972             -nan     0.1000  143.5850
##      3      872.7645             -nan     0.1000  118.7208
##      4      764.0503             -nan     0.1000  112.4616
##      5      665.5178             -nan     0.1000   92.4002
##      6      592.2673             -nan     0.1000   80.0497
##      7      536.5960             -nan     0.1000   64.6191
##      8      485.7798             -nan     0.1000   47.8213
##      9      445.0319             -nan     0.1000   41.1958
##     10      411.4633             -nan     0.1000   31.3130
##     20      232.8683             -nan     0.1000    9.9203
##     40      137.9395             -nan     0.1000    1.1614
##     60      115.5033             -nan     0.1000   -0.2852
##     80      103.5464             -nan     0.1000   -0.1662
##    100       96.6148             -nan     0.1000    0.3704
##    120       92.0743             -nan     0.1000   -0.4650
##    140       87.9470             -nan     0.1000   -0.5296
##    150       86.5364             -nan     0.1000    0.1443
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1072.0599             -nan     0.1000   83.9007
##      2      995.1452             -nan     0.1000   75.6876
##      3      930.6467             -nan     0.1000   60.1760
##      4      882.8934             -nan     0.1000   36.4684
##      5      826.8277             -nan     0.1000   57.7570
##      6      777.8295             -nan     0.1000   45.0836
##      7      738.5092             -nan     0.1000   38.4305
##      8      694.2602             -nan     0.1000   35.9653
##      9      657.8653             -nan     0.1000   14.7778
##     10      614.2662             -nan     0.1000   45.3666
##     20      381.4929             -nan     0.1000   13.7471
##     40      225.4717             -nan     0.1000    2.9268
##     60      169.7447             -nan     0.1000    1.1790
##     80      143.4027             -nan     0.1000    0.1550
##    100      130.2860             -nan     0.1000    0.3389
##    120      121.7222             -nan     0.1000    0.2099
##    140      115.8403             -nan     0.1000   -0.0558
##    150      113.2317             -nan     0.1000    0.2352
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1019.1468             -nan     0.1000   93.3516
##      2      923.9510             -nan     0.1000   96.2785
##      3      817.5182             -nan     0.1000   95.1558
##      4      746.5360             -nan     0.1000   67.5560
##      5      669.3585             -nan     0.1000   64.8072
##      6      605.2731             -nan     0.1000   61.6085
##      7      552.7118             -nan     0.1000   31.8123
##      8      509.3889             -nan     0.1000   34.3121
##      9      473.4643             -nan     0.1000   37.5760
##     10      434.2131             -nan     0.1000   32.7532
##     20      250.3380             -nan     0.1000    9.0373
##     40      149.8441             -nan     0.1000    2.3425
##     60      121.5830             -nan     0.1000    0.4301
##     80      107.6926             -nan     0.1000   -0.6998
##    100      100.4119             -nan     0.1000    0.0089
##    120       96.2707             -nan     0.1000   -0.3374
##    140       90.8735             -nan     0.1000   -0.0021
##    150       90.0521             -nan     0.1000   -0.2075
##
```

```
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1      997.9016            -nan     0.1000  156.2244
##      2      874.7602            -nan     0.1000  136.0710
##      3      766.1950            -nan     0.1000   88.8837
##      4      673.5437            -nan     0.1000   86.0353
##      5      608.7514            -nan     0.1000   68.2482
##      6      548.6146            -nan     0.1000   57.5847
##      7      501.5420            -nan     0.1000   49.3042
##      8      456.5943            -nan     0.1000   40.2833
##      9      417.2413            -nan     0.1000   37.7478
##     10      387.6704            -nan     0.1000   27.5050
##     20      216.7646            -nan     0.1000    9.6328
##     40      132.6365            -nan     0.1000    1.6443
##     60      107.6826            -nan     0.1000    0.0679
##     80       94.8867            -nan     0.1000    0.1861
##    100       86.7963            -nan     0.1000    0.4310
##    120       80.0393            -nan     0.1000    0.0909
##    140       76.8072            -nan     0.1000   -0.1429
##    150       75.2394            -nan     0.1000   -0.0434
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1080.8189            -nan     0.1000   76.6571
##      2     1003.9710            -nan     0.1000   66.6505
##      3      942.4747            -nan     0.1000   58.5403
##      4      886.9356            -nan     0.1000   55.1046
##      5      839.6075            -nan     0.1000   47.9903
##      6      781.6543            -nan     0.1000   58.4151
##      7      735.4703            -nan     0.1000   39.6462
##      8      691.4888            -nan     0.1000   42.5628
##      9      654.6201            -nan     0.1000   36.2675
##     10      622.4645            -nan     0.1000   28.5020
##     20      401.3246            -nan     0.1000    8.4799
##     40      234.4538            -nan     0.1000    3.2475
##     60      175.0800            -nan     0.1000    0.7847
##     80      150.1060            -nan     0.1000    0.2590
##    100      137.6066            -nan     0.1000   -0.6271
##    120      128.8004            -nan     0.1000    0.3464
##    140      123.6679            -nan     0.1000   -0.3460
##    150      121.3646            -nan     0.1000    0.1333
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1032.4696            -nan     0.1000  155.1064
##      2      945.9092            -nan     0.1000  107.4908
##      3      833.1954            -nan     0.1000   98.7479
##      4      748.2650            -nan     0.1000   94.3671
##      5      680.7824            -nan     0.1000   70.5340
##      6      622.6394            -nan     0.1000   63.3733
##      7      568.8359            -nan     0.1000   61.2356
##      8      521.6860            -nan     0.1000   39.0593
##      9      482.9395            -nan     0.1000   44.5384
##     10      444.5591            -nan     0.1000   37.3012
##     20      257.2536            -nan     0.1000    9.2497
##     40      156.4679            -nan     0.1000    1.0572
##     60      124.0190            -nan     0.1000    0.7324
##     80      110.4133            -nan     0.1000    0.6957
##    100      101.9957            -nan     0.1000    0.7617
##    120       95.8166            -nan     0.1000    0.0013
##    140       93.3269            -nan     0.1000   -0.2322
##    150       91.7920            -nan     0.1000   -0.2663
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1      996.8675            -nan     0.1000  155.6846
##      2      868.4262            -nan     0.1000  125.6263
##      3      766.1887            -nan     0.1000  104.5108
##      4      675.4711            -nan     0.1000   58.7944
##      5      600.3957            -nan     0.1000   68.9915
##      6      533.0195            -nan     0.1000   66.1509
##      7      477.9536            -nan     0.1000   37.5246
##      8      440.1525            -nan     0.1000   41.8343
##      9      402.6834            -nan     0.1000   37.8598
##     10      374.8409            -nan     0.1000   31.5991
##     20      210.2067            -nan     0.1000    8.9055
##     40      128.6086            -nan     0.1000   -1.2271
##     60      109.0801            -nan     0.1000   -0.2201
##     80       98.2993            -nan     0.1000   -0.1650
##    100       92.4266            -nan     0.1000    0.0777
##    120       86.3903            -nan     0.1000   -0.2130
##    140       82.5415            -nan     0.1000   -0.2469
##    150       81.0329            -nan     0.1000   -0.4306
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1222.9937            -nan     0.1000   95.5819
##      2     1145.0232            -nan     0.1000   77.1941
##      3     1077.9556            -nan     0.1000   67.2316
##      4     1009.5096            -nan     0.1000   67.9725
##      5      945.3913            -nan     0.1000   58.7099
##      6      894.1958            -nan     0.1000   54.7122
##      7      841.2722            -nan     0.1000   47.8715
##      8      798.8638            -nan     0.1000   30.1145
##      9      756.3627            -nan     0.1000   37.6571
##     10      714.7252            -nan     0.1000   42.2972
##     20      434.9873            -nan     0.1000   17.1626
##     40      248.3850            -nan     0.1000    4.5311
##     60      189.8807            -nan     0.1000    1.6512
##     80      163.0919            -nan     0.1000    0.6497
##    100      150.7166            -nan     0.1000   -0.4042
##    120      142.7196            -nan     0.1000    0.2574
##    140      136.4626            -nan     0.1000   -0.1399
##    150      133.4146            -nan     0.1000   -0.1580
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1160.9798            -nan     0.1000  137.7709
##      2     1025.0834            -nan     0.1000  130.3225
##      3      926.5422            -nan     0.1000  101.9054
##      4      835.0766            -nan     0.1000   95.1952
##      5      755.7430            -nan     0.1000   67.7841
##      6      696.4705            -nan     0.1000   59.9653
##      7      639.3003            -nan     0.1000   52.7958
##      8      578.5829            -nan     0.1000   60.5109
##      9      525.8460            -nan     0.1000   45.8725
##     10      483.9510            -nan     0.1000   44.4311
##     20      277.9536            -nan     0.1000    9.0038
##     40      169.2679            -nan     0.1000    0.9201
##     60      139.9209            -nan     0.1000   -0.2076
##     80      126.1292            -nan     0.1000   -0.7480
##    100      117.6557            -nan     0.1000    0.2180
##    120      110.9438            -nan     0.1000   -0.6432
##    140      106.7862            -nan     0.1000    0.0718
##    150      104.1988            -nan     0.1000   -0.0185
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1122.3496            -nan     0.1000  214.4010
##      2      977.3170            -nan     0.1000  141.5716
##      3      881.4311            -nan     0.1000   89.5670
##      4      802.2643            -nan     0.1000   73.8740
##      5      706.5898            -nan     0.1000  103.1031
##      6      638.2308            -nan     0.1000   74.1872
##      7      570.3551            -nan     0.1000   51.2075
##      8      521.9023            -nan     0.1000   47.8098
##      9      471.4959            -nan     0.1000   40.5367
##     10      430.4478            -nan     0.1000   38.1211
##     20      234.7109            -nan     0.1000    9.8324
##     40      139.1237            -nan     0.1000    1.2925
##     60      115.0282            -nan     0.1000    0.5032
##     80      103.9629            -nan     0.1000   -0.3077
##    100       96.6829            -nan     0.1000   -0.2997
##    120       91.8252            -nan     0.1000    0.0046
##    140       88.5128            -nan     0.1000   -0.2414
##    150       86.9650            -nan     0.1000   -0.2051
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1087.8570            -nan     0.1000   76.6095
##      2     1013.8603            -nan     0.1000   62.7495
##      3      957.5153            -nan     0.1000   55.9620
##      4      897.3468            -nan     0.1000   61.6687
##      5      836.9038            -nan     0.1000   49.7647
##      6      787.3263            -nan     0.1000   47.1981
##      7      744.5487            -nan     0.1000   36.7272
##      8      699.7224            -nan     0.1000   44.5974
##      9      664.5324            -nan     0.1000   34.5989
##     10      632.6207            -nan     0.1000   32.1634
##     20      404.4873            -nan     0.1000   14.4809
##     40      243.6616            -nan     0.1000    4.6382
##     60      187.3818            -nan     0.1000    1.8495
##     80      161.7907            -nan     0.1000    0.4776
##    100      149.1679            -nan     0.1000    0.4633
##    120      141.2548            -nan     0.1000   -0.4979
##    140      135.7785            -nan     0.1000   -0.1640
##    150      133.6173            -nan     0.1000   -0.5843
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1050.9876            -nan     0.1000  112.8077
##      2      918.7068            -nan     0.1000  129.8786
##      3      808.9025            -nan     0.1000   98.3689
##      4      728.8537            -nan     0.1000   78.2674
##      5      676.8000            -nan     0.1000   55.3235
##      6      612.2399            -nan     0.1000   54.5006
##      7      559.6181            -nan     0.1000   50.6218
##      8      515.0434            -nan     0.1000   40.8312
##      9      473.0174            -nan     0.1000   36.9899
##     10      433.1366            -nan     0.1000   33.8391
##     20      272.3469            -nan     0.1000    9.4617
##     40      170.5693            -nan     0.1000    2.2894
##     60      143.1123            -nan     0.1000    0.3532
##     80      126.9598            -nan     0.1000    0.1493
##    100      118.7461            -nan     0.1000   -0.8097
##    120      113.7615            -nan     0.1000   -0.1565
##    140      109.6232            -nan     0.1000   -0.4357
##    150      107.6110            -nan     0.1000    0.4073
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1002.9726            -nan     0.1000  130.6249
##      2      874.5304            -nan     0.1000  106.8671
##      3      784.4297            -nan     0.1000   92.7181
##      4      697.1941            -nan     0.1000   88.3228
##      5      626.8668            -nan     0.1000   74.1835
##      6      573.3715            -nan     0.1000   54.5405
##      7      514.4491            -nan     0.1000   67.7620
##      8      464.2703            -nan     0.1000   44.0149
##      9      427.8894            -nan     0.1000   36.7926
##     10      396.0215            -nan     0.1000   30.5870
##     20      228.4352            -nan     0.1000    7.3448
##     40      143.6600            -nan     0.1000    0.7433
##     60      121.9373            -nan     0.1000    0.2120
##     80      111.5679            -nan     0.1000   -0.0402
##    100      103.4978            -nan     0.1000    0.1086
##    120       97.0031            -nan     0.1000   -0.1387
##    140       92.7187            -nan     0.1000   -0.0460
##    150       90.3598            -nan     0.1000   -0.0037
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1090.7159            -nan     0.1000   84.5760
##      2     1007.2289            -nan     0.1000   74.1523
##      3      946.8949            -nan     0.1000   60.3607
##      4      887.4432            -nan     0.1000   59.7682
##      5      819.2801            -nan     0.1000   70.1452
##      6      771.3496            -nan     0.1000   47.5261
##      7      720.1783            -nan     0.1000   53.3296
##      8      681.0785            -nan     0.1000   40.7998
##      9      643.3239            -nan     0.1000   30.1461
##     10      606.5380            -nan     0.1000   36.8915
##     20      377.9292            -nan     0.1000   12.3079
##     40      217.9400            -nan     0.1000    3.2746
##     60      166.1905            -nan     0.1000    1.2989
##     80      141.4818            -nan     0.1000    0.7027
##    100      128.4313            -nan     0.1000    0.1308
##    120      119.5264            -nan     0.1000   -0.1771
##    140      113.3529            -nan     0.1000   -0.0105
##    150      110.9493            -nan     0.1000    0.0478
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1033.9575            -nan     0.1000  132.8711
##      2      923.8711            -nan     0.1000   96.0836
##      3      819.2553            -nan     0.1000   97.9891
##      4      725.4915            -nan     0.1000   69.5400
##      5      664.0824            -nan     0.1000   62.4558
##      6      606.7370            -nan     0.1000   58.9446
##      7      551.1123            -nan     0.1000   55.5651
##      8      507.4330            -nan     0.1000   44.5145
##      9      467.8108            -nan     0.1000   36.8782
##     10      434.9003            -nan     0.1000   32.6813
##     20      248.0589            -nan     0.1000   12.5799
##     40      146.4711            -nan     0.1000    1.8295
##     60      114.5459            -nan     0.1000    0.7619
##     80      102.0801            -nan     0.1000    0.0312
##    100       94.9411            -nan     0.1000    0.5516
##    120       89.8323            -nan     0.1000   -0.5575
##    140       86.1568            -nan     0.1000    0.0435
##    150       84.8165            -nan     0.1000   -0.1532
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1026.8621            -nan     0.1000  142.8041
##      2      921.2654            -nan     0.1000  108.3263
##      3      795.7200            -nan     0.1000  106.8504
##      4      696.4259            -nan     0.1000  106.4723
##      5      617.6322            -nan     0.1000   72.1743
##      6      552.1506            -nan     0.1000   65.2443
##      7      494.2715            -nan     0.1000   50.5568
##      8      445.6477            -nan     0.1000   46.1631
##      9      408.5658            -nan     0.1000   39.8022
##     10      374.8992            -nan     0.1000   30.8978
##     20      208.5083            -nan     0.1000    6.9347
##     40      122.2220            -nan     0.1000    2.0757
##     60       99.9701            -nan     0.1000    0.5794
##     80       89.6386            -nan     0.1000    0.2813
##    100       83.1020            -nan     0.1000    0.1541
##    120       78.2733            -nan     0.1000   -0.2972
##    140       75.3554            -nan     0.1000   -0.1857
##    150       73.6533            -nan     0.1000   -0.1366
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1118.8115            -nan     0.1000   73.4980
##      2     1050.4907            -nan     0.1000   66.5460
##      3      978.8147            -nan     0.1000   67.2210
##      4      917.3993            -nan     0.1000   54.8446
##      5      857.4446            -nan     0.1000   58.4640
##      6      810.0807            -nan     0.1000   42.8145
##      7      764.8915            -nan     0.1000   45.2697
##      8      717.6212            -nan     0.1000   48.6299
##      9      678.6333            -nan     0.1000   38.5026
##     10      642.8427            -nan     0.1000   36.2583
##     20      400.0696            -nan     0.1000   15.5698
##     40      232.2462            -nan     0.1000    3.8881
##     60      174.7613            -nan     0.1000    1.5945
##     80      148.1350            -nan     0.1000    0.5106
##    100      135.2250            -nan     0.1000   -0.9972
##    120      126.5791            -nan     0.1000    0.3248
##    140      119.9147            -nan     0.1000    0.1349
##    150      117.7438            -nan     0.1000    0.0888
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1062.1767            -nan     0.1000  153.5348
##      2      936.4652            -nan     0.1000  115.1786
##      3      829.3559            -nan     0.1000   85.4330
##      4      757.2288            -nan     0.1000   79.2473
##      5      700.1942            -nan     0.1000   61.7006
##      6      636.2802            -nan     0.1000   66.7213
##      7      580.7349            -nan     0.1000   56.5523
##      8      534.5268            -nan     0.1000   46.2899
##      9      498.0534            -nan     0.1000   35.5052
##     10      458.5808            -nan     0.1000   36.8635
##     20      272.1561            -nan     0.1000   10.5912
##     40      163.0717            -nan     0.1000    1.0363
##     60      126.9545            -nan     0.1000    1.4551
##     80      113.7320            -nan     0.1000   -0.0505
##    100      106.1635            -nan     0.1000   -0.7638
##    120      100.3572            -nan     0.1000    0.5649
##    140       95.7085            -nan     0.1000   -0.1186
##    150       93.0152            -nan     0.1000    0.3598
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1041.6123            -nan     0.1000  154.3690
##      2      914.0338            -nan     0.1000  142.5481
##      3      801.1364            -nan     0.1000  110.1066
##      4      733.4377            -nan     0.1000   74.4354
##      5      652.7770            -nan     0.1000   91.6788
##      6      578.6338            -nan     0.1000   59.0238
##      7      526.6763            -nan     0.1000   49.7396
##      8      479.9661            -nan     0.1000   42.8199
##      9      438.8906            -nan     0.1000   41.4579
##     10      404.4224            -nan     0.1000   35.9367
##     20      229.6770            -nan     0.1000    9.7288
##     40      135.5758            -nan     0.1000    0.8887
##     60      109.8398            -nan     0.1000   -0.2751
##     80       97.5181            -nan     0.1000   -0.1177
##    100       91.6485            -nan     0.1000   -0.3932
##    120       85.1088            -nan     0.1000   -0.1882
##    140       80.8995            -nan     0.1000   -0.4833
##    150       78.4903            -nan     0.1000   -0.2523
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1119.8773            -nan     0.1000   94.3423
##      2     1036.5403            -nan     0.1000   84.1755
##      3      967.3030            -nan     0.1000   68.0679
##      4      900.4328            -nan     0.1000   51.4887
##      5      840.7201            -nan     0.1000   57.2646
##      6      789.3604            -nan     0.1000   53.1029
##      7      737.3305            -nan     0.1000   48.8495
##      8      694.6946            -nan     0.1000   46.8030
##      9      651.7255            -nan     0.1000   37.3301
##     10      615.7655            -nan     0.1000   37.5008
##     20      383.5992            -nan     0.1000   11.8737
##     40      228.2604            -nan     0.1000    2.4331
##     60      178.3682            -nan     0.1000    1.1799
##     80      152.9885            -nan     0.1000    0.4506
##    100      139.4953            -nan     0.1000    0.1046
##    120      131.4240            -nan     0.1000    0.2497
##    140      125.9992            -nan     0.1000   -0.6988
##    150      123.9954            -nan     0.1000    0.1049
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1056.6943            -nan     0.1000  152.1538
##      2      922.9485            -nan     0.1000  127.0554
##      3      812.9224            -nan     0.1000  112.0540
##      4      735.7370            -nan     0.1000   77.1514
##      5      660.4394            -nan     0.1000   77.7973
##      6      594.5295            -nan     0.1000   54.8795
##      7      538.1276            -nan     0.1000   50.0000
##      8      496.2987            -nan     0.1000   41.3740
##      9      463.3502            -nan     0.1000   29.0453
##     10      423.1220            -nan     0.1000   32.9575
##     20      254.4723            -nan     0.1000   10.8771
##     40      157.7539            -nan     0.1000    3.1032
##     60      129.3769            -nan     0.1000    0.6312
##     80      115.9494            -nan     0.1000    0.5027
##    100      109.1067            -nan     0.1000   -0.1916
##    120      103.6767            -nan     0.1000   -0.1559
##    140      100.4952            -nan     0.1000   -0.0890
##    150       98.7492            -nan     0.1000   -0.2977
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1048.6867            -nan     0.1000  169.7189
##      2      898.1875            -nan     0.1000  132.8233
##      3      779.0176            -nan     0.1000  115.3169
##      4      688.4945            -nan     0.1000   76.3549
##      5      601.5160            -nan     0.1000   76.0706
##      6      535.5268            -nan     0.1000   49.9857
##      7      491.4052            -nan     0.1000   44.9608
##      8      456.8617            -nan     0.1000   33.7188
##      9      427.1252            -nan     0.1000   27.1048
##     10      396.9068            -nan     0.1000   34.3282
##     20      227.6345            -nan     0.1000    7.7327
##     40      139.1342            -nan     0.1000    2.4652
##     60      116.2420            -nan     0.1000    0.1765
##     80      104.1271            -nan     0.1000   -0.5082
##    100       96.7440            -nan     0.1000   -0.1467
##    120       92.1058            -nan     0.1000   -0.1483
##    140       87.7991            -nan     0.1000    0.0628
##    150       86.2169            -nan     0.1000   -0.0998
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1189.0101            -nan     0.1000   86.6900
##      2     1114.6414            -nan     0.1000   71.3947
##      3     1047.4181            -nan     0.1000   57.8647
##      4      977.1987            -nan     0.1000   66.0326
##      5      907.3896            -nan     0.1000   67.8968
##      6      851.5658            -nan     0.1000   54.0091
##      7      800.4883            -nan     0.1000   43.4781
##      8      753.3136            -nan     0.1000   40.4555
##      9      709.8473            -nan     0.1000   39.5049
##     10      668.1243            -nan     0.1000   37.6030
##     20      423.7775            -nan     0.1000   18.7096
##     40      248.4562            -nan     0.1000    3.1495
##     60      192.5803            -nan     0.1000    1.5092
##     80      169.4225            -nan     0.1000    0.4061
##    100      156.9656            -nan     0.1000    0.2653
##    120      149.3569            -nan     0.1000    0.0663
##    140      145.4897            -nan     0.1000   -0.1711
##    150      143.3884            -nan     0.1000   -0.4252
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1129.1701            -nan     0.1000  153.7598
##      2      996.7433            -nan     0.1000   97.6723
##      3      909.4208            -nan     0.1000   88.9440
##      4      821.4093            -nan     0.1000   82.8959
##      5      755.1422            -nan     0.1000   67.1834
##      6      678.6369            -nan     0.1000   67.5101
##      7      618.9197            -nan     0.1000   56.0494
##      8      569.8699            -nan     0.1000   52.9390
##      9      533.0902            -nan     0.1000   36.0775
##     10      490.8521            -nan     0.1000   41.1104
##     20      279.8185            -nan     0.1000    8.8339
##     40      181.4204            -nan     0.1000    1.5549
##     60      150.0737            -nan     0.1000    1.6910
##     80      137.2608            -nan     0.1000    0.7824
##    100      129.9877            -nan     0.1000   -0.4570
##    120      123.8775            -nan     0.1000   -0.3129
##    140      118.0144            -nan     0.1000   -0.7412
##    150      115.0476            -nan     0.1000   -0.3169
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1106.8309            -nan     0.1000  137.4255
##      2      983.8373            -nan     0.1000  111.8664
##      3      876.5559            -nan     0.1000  110.1780
##      4      766.9048            -nan     0.1000  109.8097
##      5      682.1685            -nan     0.1000   80.4737
##      6      622.5092            -nan     0.1000   66.1048
##      7      550.4590            -nan     0.1000   62.3545
##      8      498.6682            -nan     0.1000   46.0724
##      9      457.5230            -nan     0.1000   46.5795
##     10      421.0962            -nan     0.1000   37.5097
##     20      236.7550            -nan     0.1000    9.0588
##     40      151.0315            -nan     0.1000    0.7579
##     60      127.0778            -nan     0.1000   -0.1092
##     80      116.4214            -nan     0.1000   -0.0738
##    100      107.3310            -nan     0.1000   -0.5775
##    120      102.4719            -nan     0.1000   -0.3353
##    140       96.2524            -nan     0.1000   -0.0157
##    150       94.1987            -nan     0.1000    0.1255
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1283.6954            -nan     0.1000   73.1715
##      2     1182.6265            -nan     0.1000   84.5721
##      3     1092.3751            -nan     0.1000   87.0078
##      4     1020.7277            -nan     0.1000   66.1521
##      5      954.5623            -nan     0.1000   65.1395
##      6      892.8784            -nan     0.1000   38.6726
##      7      839.0687            -nan     0.1000   52.9767
##      8      785.7557            -nan     0.1000   57.1875
##      9      743.5452            -nan     0.1000   39.0069
##     10      695.9698            -nan     0.1000   48.5670
##     20      422.0979            -nan     0.1000   15.6932
##     40      243.9402            -nan     0.1000    4.0555
##     60      186.8147            -nan     0.1000    0.8337
##     80      161.0412            -nan     0.1000    0.2119
##    100      147.5159            -nan     0.1000    0.2091
##    120      138.3987            -nan     0.1000    0.0832
##    140      131.6827            -nan     0.1000    0.1823
##    150      128.7122            -nan     0.1000   -0.0164
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1207.7910            -nan     0.1000  180.1243
##      2     1063.2926            -nan     0.1000  153.4980
##      3      965.0687            -nan     0.1000   85.7630
##      4      864.6020            -nan     0.1000   91.2689
##      5      773.1352            -nan     0.1000   82.4426
##      6      700.6816            -nan     0.1000   69.2203
##      7      631.2889            -nan     0.1000   68.3590
##      8      573.0636            -nan     0.1000   51.0187
##      9      528.0273            -nan     0.1000   45.9456
##     10      476.1582            -nan     0.1000   44.3333
##     20      278.1279            -nan     0.1000    9.1232
##     40      169.9533            -nan     0.1000    1.3212
##     60      137.5625            -nan     0.1000    0.8528
##     80      123.0038            -nan     0.1000   -0.2596
##    100      112.5488            -nan     0.1000    0.2349
##    120      105.2482            -nan     0.1000   -0.0700
##    140      101.6530            -nan     0.1000   -0.3782
##    150      100.3467            -nan     0.1000   -0.7668
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1187.7043            -nan     0.1000  214.3587
##      2     1020.9794            -nan     0.1000  181.5930
##      3      893.9061            -nan     0.1000  127.2004
##      4      778.8480            -nan     0.1000  120.6036
##      5      695.0268            -nan     0.1000   74.5797
##      6      629.3644            -nan     0.1000   77.4514
##      7      561.2605            -nan     0.1000   67.4979
##      8      510.4674            -nan     0.1000   53.8901
##      9      459.3352            -nan     0.1000   37.7979
##     10      416.3479            -nan     0.1000   41.0710
##     20      227.3097            -nan     0.1000    6.8951
##     40      136.2936            -nan     0.1000    1.5643
##     60      115.3820            -nan     0.1000    0.0036
##     80      103.7335            -nan     0.1000   -0.0722
##    100       96.6125            -nan     0.1000    0.0211
##    120       92.4467            -nan     0.1000   -0.1759
##    140       88.4003            -nan     0.1000   -0.2170
##    150       86.1169            -nan     0.1000   -0.0322
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1210.0056            -nan     0.1000   77.0098
##      2     1131.9875            -nan     0.1000   77.4601
##      3     1050.1754            -nan     0.1000   78.9251
##      4      985.7537            -nan     0.1000   63.0267
##      5      929.2235            -nan     0.1000   51.8651
##      6      868.4312            -nan     0.1000   66.4035
##      7      813.4592            -nan     0.1000   52.3478
##      8      772.3243            -nan     0.1000   43.1009
##      9      738.1129            -nan     0.1000   33.0682
##     10      699.9654            -nan     0.1000   40.1154
##     20      434.8572            -nan     0.1000   14.7241
##     40      252.9659            -nan     0.1000    4.0820
##     60      190.3498            -nan     0.1000    2.0213
##     80      162.8234            -nan     0.1000    0.6628
##    100      150.7828            -nan     0.1000    0.5502
##    120      142.9481            -nan     0.1000    0.0537
##    140      137.5727            -nan     0.1000   -0.5494
##    150      135.5533            -nan     0.1000    0.0043
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1144.5054            -nan     0.1000  171.3193
##      2     1026.1129            -nan     0.1000  122.7750
##      3      929.5790            -nan     0.1000   92.9228
##      4      835.4790            -nan     0.1000   75.4115
##      5      752.1271            -nan     0.1000   78.2724
##      6      683.9247            -nan     0.1000   71.9112
##      7      620.0264            -nan     0.1000   54.5971
##      8      565.8734            -nan     0.1000   40.3096
##      9      516.9392            -nan     0.1000   38.0251
##     10      484.2238            -nan     0.1000   36.4699
##     20      292.2535            -nan     0.1000   10.8410
##     40      165.6017            -nan     0.1000    2.9954
##     60      134.2776            -nan     0.1000    0.5575
##     80      120.1004            -nan     0.1000    0.0713
##    100      111.6263            -nan     0.1000   -1.0180
##    120      105.9832            -nan     0.1000   -0.2969
##    140      102.5158            -nan     0.1000    0.0533
##    150      100.7794            -nan     0.1000   -0.2743
##
```

```
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1163.8655            -nan     0.1000  156.2903
##      2     1016.5769            -nan     0.1000  143.8181
##      3      882.9052            -nan     0.1000  133.6532
##      4      772.9999            -nan     0.1000   83.3790
##      5      688.3052            -nan     0.1000   60.3592
##      6      613.6813            -nan     0.1000   68.7803
##      7      550.7211            -nan     0.1000   64.4275
##      8      497.8653            -nan     0.1000   47.6486
##      9      458.5626            -nan     0.1000   40.8449
##     10      420.3436            -nan     0.1000   30.5602
##     20      229.2189            -nan     0.1000   15.5717
##     40      134.3119            -nan     0.1000    0.8417
##     60      112.1139            -nan     0.1000    1.0587
##     80       99.2406            -nan     0.1000    0.1316
##    100       92.5674            -nan     0.1000   -0.1656
##    120       87.5723            -nan     0.1000    0.1431
##    140       83.9197            -nan     0.1000   -0.3731
##    150       81.6334            -nan     0.1000    0.2738
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1     1066.3687            -nan     0.1000  169.8292
##      2      927.1047            -nan     0.1000  114.6841
##      3      807.6555            -nan     0.1000  121.2462
##      4      718.3953            -nan     0.1000   99.4117
##      5      634.5350            -nan     0.1000   79.5987
##      6      573.8356            -nan     0.1000   69.3062
##      7      515.3659            -nan     0.1000   47.3729
##      8      470.2866            -nan     0.1000   36.9176
##      9      429.8505            -nan     0.1000   39.8279
##     10      400.3352            -nan     0.1000   30.4731
##     20      229.6228            -nan     0.1000    8.5911
##     40      144.8718            -nan     0.1000    1.4341
##     60      123.6587            -nan     0.1000    1.1849
##     80      111.3196            -nan     0.1000    0.1940
##    100      105.9478            -nan     0.1000   -0.0948
##    120      101.1540            -nan     0.1000   -0.2309
##    140       97.2260            -nan     0.1000   -0.1688
##    150       95.4646            -nan     0.1000   -0.2985
```

The `summary()` function also provides a relative influence plot and also outputs the relative influence statistics.

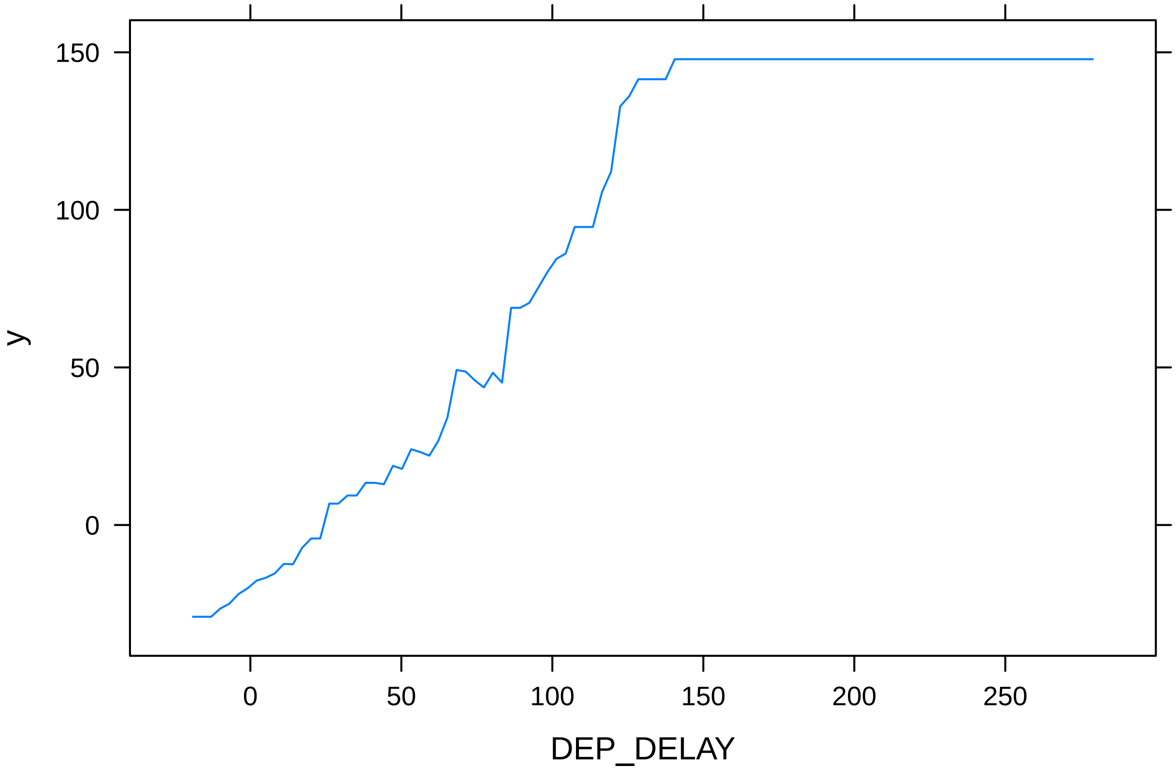
```
summary(boost.delay)
```



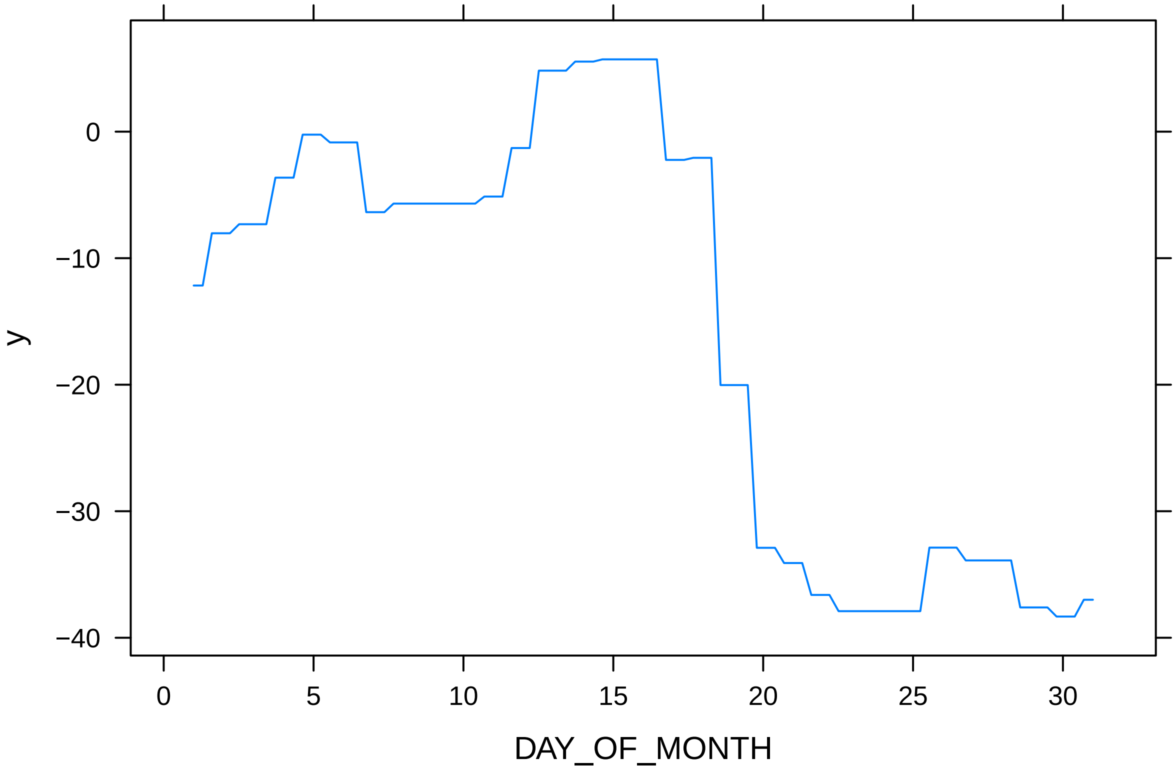
```
##                                   var    rel.inf
## DEP_DELAY                   DEP_DELAY 56.5279213
## DAY_OF_MONTH             DAY_OF_MONTH 25.0608132
## NAS_DELAY                   NAS_DELAY  9.3867001
## TAXI_OUT                     TAXI_OUT  5.0157480
## TAXI_IN                       TAXI_IN  3.0135950
## LATE_AIRCRAFT_DELAY LATE_AIRCRAFT_DELAY  0.5862760
## CARRIER_DELAY           CARRIER_DELAY  0.4089464
```

We see that DEP_DELAY and DAY_OF_MONTH are by far the most important variables. We can also produce *partial dependence plots* for these two variables. These plots illustrate the marginal effect of the selected variables on the response after integrating out the other variables.

```
par(mfrow = c(1,2))
plot(boost.delay, i = "DEP_DELAY")
```



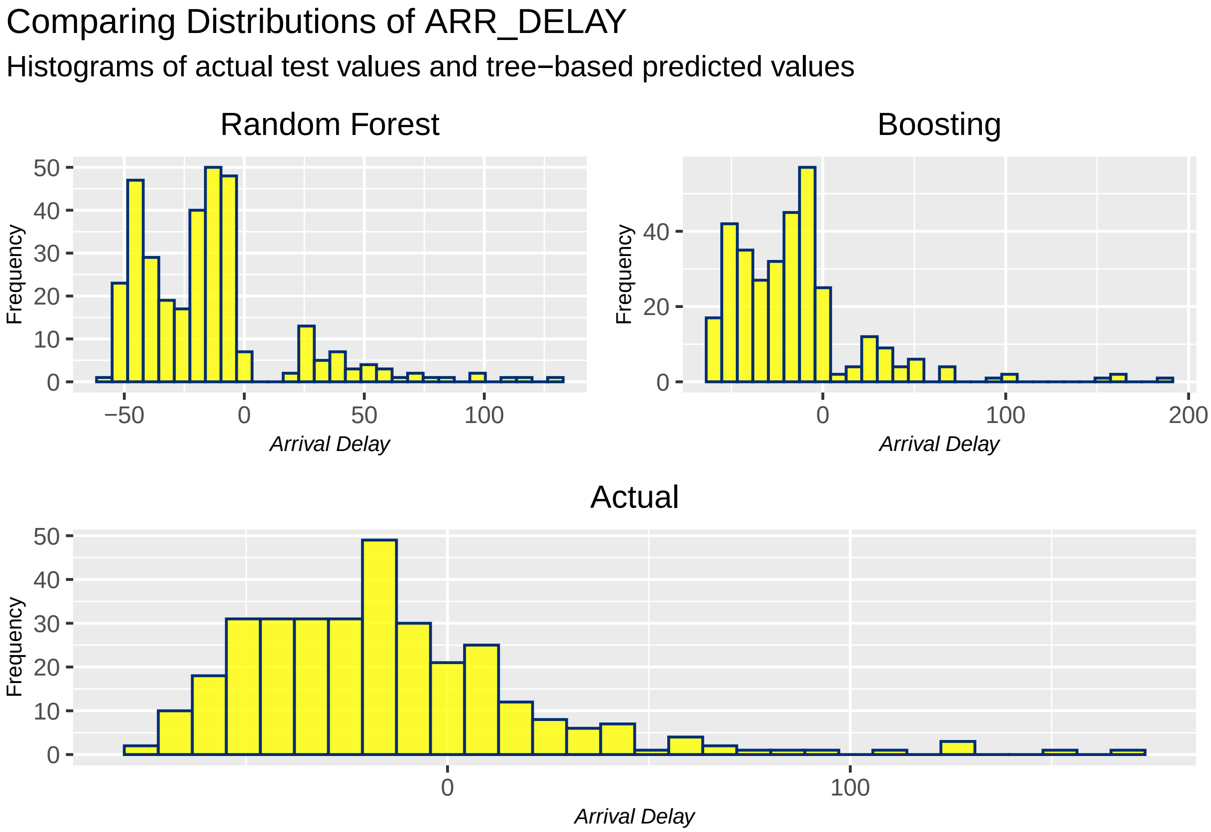
```r
plot(boost.delay, i = "DAY_OF_MONTH")
```



Trees Test Error Metrics & Predictions

```r
# predictions
## random forest
yhat.rf <- predict(rf.delay, newdata = test)
## boosting
yhat.boost <- predict(boost.delay, newdata =test,
                      n.trees = 150)

## histogram of predictions vs. actual
# actual ARR_DELAY in test set
ptest_actual <- ggplot(data = test, aes(x = ARR_DELAY)) +
  geom_histogram(fill = "#FFFF00", color = "#002D72", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "Actual") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# predicted ARR_DELAY in test set -- baseline lm
ptest_rf <- ggplot(data = test, aes(x = yhat.rf)) +
  geom_histogram(fill = "#FFFF00", color = "#002D72", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "Random Forest") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))

# predicted ARR_DELAY in test set -- lm with log-trans
ptest_boost <- ggplot(data = test, aes(x = yhat.boost)) +
  geom_histogram(fill = "#FFFF00", color = "#002D72", alpha = 0.8) +
  labs(x = "Arrival Delay",
       y = "Frequency",
       title = "Boosting") +
  theme(plot.title = element_text(size = 12,hjust = 0.5),
        plot.subtitle = element_text(hjust = 0.5),
        axis.title.x.bottom = element_text(size = 8, face = "italic"),
        axis.title.y.left = element_text(size = 8))


# grid.arrange(ptest_actual, ptest_rf, ptest_boost, ncol = 2,
#              width = c(2,1,1),
#              layout_matrix = rbind(c(1,2),
#                                    c(1, 3)))

trees_patchwork <- (ptest_rf | ptest_boost) / ptest_actual
trees_patchwork + plot_annotation(
  title = 'Comparing Distributions of ARR_DELAY',
  subtitle = 'Histograms of actual test values and tree-based predicted values'
)
```

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



Comparing Distributions of ARR_DELAY

Histograms of actual test values and tree−based predicted values

```
# test MSE calculations
rf.MSE <- sum((test$ARR_DELAY - yhat.rf)^2, na.rm=T)/length(test$ARR_DELAY)
rf.MSE
```

```
## [1] 155.0148
```

```
boost_MSE <- sum((test$ARR_DELAY-yhat.boost)^2, na.rm = T)/length(test$ARR_DELAY)
boost_MSE
```

```
## [1] 129.7965
```

Test Error Tables

```
customGreen = "#71CA97"
customRed = "#ff7f7f"

library(formattable)
```

```
##
## Attaching package: 'formattable'

## The following object is masked from 'package:bst':
##
##     gradient

## The following object is masked from 'package:MASS':
##
##     area

## The following object is masked from 'package:patchwork':
##
##     area
```

```
options(scipen = 5, digits = 4)
model.names <- c("Baseline Linear", "Selected Linear w/ Log-Transformed Predictors", "Selected Linear w
model.types <- c("Multiple Linear Regression", "Multiple Linear Regression", "Multiple Linear Regressio

#model4.ints <- c("FALSE", "FALSE", "FALSE", "FALSE")

model.mse <- c(plain_linear_model_MSE, log_linear_MSE,
                    bc_adj_linear_model_MSE, gam_MSE,
                    gambc_MSE, rf.MSE, boost_MSE)
model.mse.char <- c("322.46", "333.90", "334.92", "312.30", "317.45", "155.01", "129.80")

#model4.cvmse_var <- c(mlr4_1_cv, mlr4_4_bc_cv, ridge.mom4.cvmse, gam4_bc_gcv)
#model4.cvmse <- c(2.284e+20, "25.66", 25.62, 25.79)


pctchange_1 <- round(-((log_linear_MSE - plain_linear_model_MSE)/plain_linear_model_MSE)*100, digits = 
pctchange_2 <- round(-((bc_adj_linear_model_MSE - plain_linear_model_MSE)/plain_linear_model_MSE)*100, 
pctchange_3 <- round(-((gam_MSE - plain_linear_model_MSE)/plain_linear_model_MSE)*100, digits = 4)
pctchange_4 <- round(-((gambc_MSE - plain_linear_model_MSE)/plain_linear_model_MSE)*100, digits = 4)
pctchange_5 <- round(-((rf.MSE - plain_linear_model_MSE)/plain_linear_model_MSE)*100, digits = 4)
pctchange_6 <- round(-((boost_MSE - plain_linear_model_MSE)/plain_linear_model_MSE)*100, digits = 4)


model.pctchange <- c("---", pctchange_1, pctchange_2, pctchange_3, pctchange_4, pctchange_5, pctchange_

errors.df <- data.frame(model.names,
                         model.types,
                         model.mse.char,
                        model.pctchange
                         )

 #model4.ints,
#model4.cvmse,
                         #model4.pctchange
```

```
#colnames(errors.df4) <- c("Model Name", "Model Type", "Interactions?", "Model MSE", "Model CV MSE", "M
errors.df
```

```
##                                      model.names                model.types
## 1                               Baseline Linear Multiple Linear Regression
## 2 Selected Linear w/ Log-Transformed Predictors Multiple Linear Regression
## 3                    Selected Linear w/ Box-Cox Multiple Linear Regression
## 4                                           GAM Generalized Additive Model
## 5                                GAM w/ Box-Cox Generalized Additive Model
## 6                                 Random Forest      Tree-Based Regression
## 7                                      Boosting     Tree-Based Regression
##   model.mse.char model.pctchange
## 1         322.46             ---
## 2         333.90         -3.5469
## 3         334.92         -3.8652
## 4         312.30          3.1519
## 5         317.45          1.5521
## 6         155.01         51.9272
## 7         129.80         59.7479
```

```
mlr.model.names <- c("Baseline Linear", "Selected Linear w/ Log-Transformed Predictors", "Selected Linea
mlr.mse.char <- c("322.46", "333.90", "334.92")

mlr.error.df <- data.frame(mlr.model.names, mlr.mse.char)

formattable(mlr.error.df,
            col.names = c("Model Name", "Model MSE"),
            list(
  mlr.model.names = formatter("span", style = x ~ ifelse(x == "Baseline Linear",
    style(color = "purple", font.weight = "bold"), NA)),
  mlr.mse.char = formatter("span", style = x ~ ifelse(x == "322.46",
    style(color = "purple", font.weight = "bold"), NA))
            ))
```

Model Name

Model MSE

Baseline Linear

322.46

Selected Linear w/ Log-Transformed Predictors

333.90

Selected Linear w/ Box-Cox

334.92

```
gam.model.names <- c("GAM", "GAM w/ Box-Cox")
gam.mse.char <- c("312.30", "317.45")

gam.error.df <- data.frame(gam.model.names, gam.mse.char)

formattable(gam.error.df,
            col.names = c("Model Name", "Model MSE"),
             list(
  gam.model.names = formatter("span", style = x ~ ifelse(x == "GAM",
    style(color = "purple", font.weight = "bold"), NA)),
  gam.mse.char = formatter("span", style = x ~ ifelse(x == "312.30",
    style(color = "purple", font.weight = "bold"), NA))
             ))
```

Model Name

Model MSE

GAM

312.30

GAM w/ Box-Cox

317.45

```
tree.model.names <- c("Random Forest", "Boosting")
tree.mse.char <- c("155.01", "129.80")

tree.error.df <- data.frame(tree.model.names, tree.mse.char)

formattable(tree.error.df,
             col.names = c("Model Name", "Model MSE"),
             list(
  tree.model.names = formatter("span", style = x ~ ifelse(x == "Boosting",
    style(color = "purple", font.weight = "bold"), NA)),
  tree.mse.char = formatter("span", style = x ~ ifelse(x == "129.80",
    style(color = "purple", font.weight = "bold"), NA))
             ))
```

Model Name

Model MSE

Random Forest

155.01

Boosting

129.80

```
formattable(errors.df,
             col.names = c("Model Name", "Model Type", "Model MSE", "Model Percent Improvement"),
             list(
  model.names = formatter("span", style = x ~ ifelse(x == "Boosting",
    style(color = "purple", font.weight = "bold"), NA)),
  model.mse.char = formatter("span", style = x ~ ifelse(x == "129.80",
    style(color = "purple", font.weight = "bold"), NA)),
  model.types = formatter("span", style = x ~ ifelse(x == "Tree-Based Regression ",
    style(color = "purple", font.weight = "bold"), NA)),
  model.pctchange = formatter("span",
                                      style = x ~ style(font.weight = "bold",
                                                         color = ifelse(x == "---", "black",
                                                                     ifelse(x > 0, customGreen, ifelse(x < 0
                                      x ~ icontext(ifelse(x>0, "arrow-up", "arrow-down"), x)
```

```
                                                  )
))
```

Model Name

Model Type

Model MSE

Model Percent Improvement

Baseline Linear

Multiple Linear Regression

322.46

—

Selected Linear w/ Log-Transformed Predictors

Multiple Linear Regression

333.90

-3.5469

Selected Linear w/ Box-Cox

Multiple Linear Regression

334.92

-3.8652

GAM

Generalized Additive Model

312.30

3.1519

GAM w/ Box-Cox

Generalized Additive Model

317.45

1.5521

Random Forest

Tree-Based Regression

155.01

51.9272

Boosting

Tree-Based Regression

129.80

59.7479