MS&E 226 Project

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IMPORT DATA AND SPLIT INTO TRAIN AND HOLDOUT

```
NFL_DATA <- read.csv(file = "train.csv", header = TRUE, sep=",")
NFL_DATA_Run_Observations <- NFL_DATA[(NFL_DATA$NflIdRusher == NFL_DATA$NflId)    , ]

# split 80:20 for training:test
set.seed(121)
training_data = sample(nrow(NFL_DATA_Run_Observations), size = nrow(NFL_DATA_Run_Observations) * 0.8)
NFL_DATA_Train = NFL_DATA_Run_Observations[training_data, ]
NFL_DATA_Holdout = NFL_DATA_Run_Observations[-training_data, ] # holdout is remaining indices
```

DATA MANIPULATION AND CLEANING

Adding the covariates that we want to include, and modififying the dataframe

```
NFL_DATA_TRAIN_Modified <- NFL_DATA_Train

# Function to take the difference in time from the dataframe
timeDifference <- function(time) {
  num <- gsub("[:]", "" , str_sub(time, 12, 19), perl=TRUE)
  hr <- ifelse(str_sub(num, 1, 2) == "00", 24, as.numeric(str_sub(num, 1, 2)))
  min <- as.numeric(str_sub(num, 3, 4))
  sec <- as.numeric(str_sub(num, 5, 6))
  newTime <- 3600*hr + 60 * min + sec
  return(newTime)
}
# Add Time_Difference between the snap and the handoff
NFL_DATA_TRAIN_Modified$TimeDifference <-
  timeDifference(NFL_DATA_TRAIN_Modified$TimeHandoff) - timeDifference(NFL_DATA_TRAIN_Modified$TimeSnap

# Add the Difference in Score by home score - visitor score
# Difference in Score (Pair with which team is winning (HomeScore-AwayScore))
NFL_DATA_TRAIN_Modified$HomeScoreAdvantage <-
  NFL_DATA_TRAIN_Modified$HomeScoreBeforePlay - NFL_DATA_TRAIN_Modified$VisitorScoreBeforePlay

# Add the age of the running player

# Change the birth dates to strings
NFL_DATA_TRAIN_Modified$PlayerBirthDate = as.character(NFL_DATA_TRAIN_Modified$PlayerBirthDate)
# Grab the Year for each of the running player
Birth_Year = str_sub(NFL_DATA_TRAIN_Modified$PlayerBirthDate, 7, 11)
# Grab Month of each running player
Birth_Month = str_sub(NFL_DATA_TRAIN_Modified$PlayerBirthDate, 1, 2)
# If Born in July (07) Have lived 5/12 of a year. ie (12 - (Birth_Month)) / 12
How_Much_Of_Year_Lived = (12 - as.numeric(Birth_Month)) / 12
Years_Lived = NFL_DATA_TRAIN_Modified$Season - as.numeric(Birth_Year)
```

```
Total_Years_Lived = Years_Lived + How_Much_Of_Year_Lived
NFL_DATA_TRAIN_Modified$PlayerAge = Total_Years_Lived

# Change HEIGHT to inches and continuous
Feet = as.numeric(str_sub(NFL_DATA_TRAIN_Modified$PlayerHeight, 1, 1))
Inches = as.numeric(str_sub(NFL_DATA_TRAIN_Modified$PlayerHeight, 3, 4))
Heights = (Feet * 12) + Inches
NFL_DATA_TRAIN_Modified$PlayerHeight = Heights

# Changes GAMECLOCK to Seconds.

NFL_DATA_TRAIN_Modified$GameClock = as.numeric(NFL_DATA_TRAIN_Modified$GameClock)

# FACTORING VARIABLES INTO CATEGORICAL

# Factor OFFENSE FORMATION
NFL_DATA_TRAIN_Modified$OffenseFormation = factor(NFL_DATA_TRAIN_Modified$OffenseFormation)

# DEFENDERS IN BOX (Need Categorical and Ordinal)
NFL_DATA_TRAIN_Modified$DefendersInTheBox = factor(NFL_DATA_TRAIN_Modified$DefendersInTheBox)


# REFACTOR DEFENDER IN BOX TO INCLUDE ORDINALITY
# Leaving them unordered was for graphs above, to look good
NFL_DATA_TRAIN_Modified$DefendersInTheBox = factor(NFL_DATA_TRAIN_Modified$DefendersInTheBox, order = TR
```

SELECTION OF COVARIATES FOR ANALYSIS

```
# Drop columns that are collinear, or we think are not critical to our model
NFL_DATA_TRAIN_Filtered = select(NFL_DATA_TRAIN_Modified,
                                 -GameId, -PlayId, -Team, -S, -A, -Dis,
                                 -Orientation, -Dir, -DisplayName, -JerseyNumber,
                                 -YardLine, -FieldPosition, -HomeScoreBeforePlay,
                                 -VisitorScoreBeforePlay, -NflId, -TimeHandoff,
                                 -TimeSnap, -PlayerBirthDate, -PlayerCollegeName,
                                 -Location,-WindSpeed, -WindDirection, -StadiumType,
                                 -Turf,-GameWeather,-NflIdRusher, -Stadium)
# Turf and stadium type all captured in stadium
# View(NFL_DATA_TRAIN_Filtered) # drop game weather, captured in Week, and Stadium. Also too many missi
```

NOW THAT HAVE SELECTED COVARIATES. MORE DATA CLEANING, FACTORING, ETC...

```
# Need to count how many NA / Empty cells there are for each column
# summary(NFL_DATA_TRAIN_Filtered)  # changed empty to NA when reading in file
# GameWeather, Temperature, Humidy all have missing or NA data
# sum(is.na(NFL_DATA_TRAIN_Filtered$GameWeather))
# sum(NFL_DATA_TRAIN_Filtered$GameWeather == "")
```

```r
# Factor the DOWNS, Ordinally
NFL_DATA_TRAIN_Filtered$Down = factor(as.numeric(NFL_DATA_TRAIN_Filtered$Down), order = TRUE, levels = c

# Player WEIGHT
NFL_DATA_TRAIN_Filtered$PlayerWeight = as.numeric(NFL_DATA_TRAIN_Filtered$PlayerWeight)

# Factor POSITION
NFL_DATA_TRAIN_Filtered$Position = factor(NFL_DATA_TRAIN_Filtered$Position)

# factor POSITION
NFL_DATA_TRAIN_Filtered$Position = factor(NFL_DATA_TRAIN_Filtered$Position)

# factor SEASON
NFL_DATA_TRAIN_Filtered$Season = factor(NFL_DATA_TRAIN_Filtered$Season)


# DATA CLEANING (REMOVING NA'S, and observations that happen less than 3 times)
# This was causing issues where one fold has a factor but another fold does not

# Need to delete a row within a column if there is just 1 special case. (Minimun 3 observations)

# DefensePersonnel (reduces observations by 11)
NFL_DATA_TRAIN_Filtered = NFL_DATA_TRAIN_Filtered[unsplit(table(NFL_DATA_TRAIN_Filtered$DefensePersonnel

# Same for OffensePersonnel (reduces by 18 observations)
NFL_DATA_TRAIN_Filtered = NFL_DATA_TRAIN_Filtered[unsplit(table(NFL_DATA_TRAIN_Filtered$OffensePersonnel

# Same for Position
NFL_DATA_TRAIN_Filtered = NFL_DATA_TRAIN_Filtered[unsplit(table(NFL_DATA_TRAIN_Filtered$Position), NFL_D

# Same for Defenders In the Box
NFL_DATA_TRAIN_Filtered = NFL_DATA_TRAIN_Filtered[unsplit(table(NFL_DATA_TRAIN_Filtered$DefendersInTheBo

# Same for Offense Formation
NFL_DATA_TRAIN_Filtered = NFL_DATA_TRAIN_Filtered[unsplit(table(NFL_DATA_TRAIN_Filtered$OffenseFormation

# Need to remove NA Rows: Still 16,758 observations out of ~18,000
NFL_DATA_TRAIN_Filtered_Final <- na.omit(NFL_DATA_TRAIN_Filtered)
# View(NFL_DATA_TRAIN_Filtered_Final)
```

BEGINNING OF ANALYSIS

Regression with all Covariates

```r
NFL_Train_Total_Model = lm(Yards ~ ., data=NFL_DATA_TRAIN_Filtered_Final)
NFL_Train_Total_Model.cv = cvFit(NFL_Train_Total_Model, data=NFL_DATA_TRAIN_Filtered_Final, y=NFL_DATA_T
NFL_Train_Total_Model.cv # RMSE= 6.388  # May have collinearity
```

```
## 10-fold CV results:
##     CV
## 6.3971
```

```
NFL_Train_Total_Model$coefficients
```

```
##                                (Intercept)
##                                 2.52108549
##                                          X
##                                -0.00119220
##                                          Y
##                                 0.01045713
##                                 Season2018
##                                 0.31226786
##                                    Quarter
##                                -0.02536574
##                                  GameClock
##                                 0.00056159
##                           PossessionTeamATL
##                                 0.96758290
##                           PossessionTeamBLT
##                                 1.48581587
##                           PossessionTeamBUF
##                                 0.31194614
##                           PossessionTeamCAR
##                                 1.01634540
##                           PossessionTeamCHI
##                                 0.86344590
##                           PossessionTeamCIN
##                                -0.94385118
##                           PossessionTeamCLV
##                                 0.73746082
##                           PossessionTeamDAL
##                                 0.90799918
##                           PossessionTeamDEN
##                                 0.58150661
##                           PossessionTeamDET
##                                 0.53371977
##                            PossessionTeamGB
##                                 1.00583198
##                           PossessionTeamHST
##                                 1.00245926
##                           PossessionTeamIND
##                                 0.90109676
##                           PossessionTeamJAX
##                                 0.40757723
##                            PossessionTeamKC
##                                 0.78847864
##                            PossessionTeamLA
##                                 0.76652796
##                           PossessionTeamLAC
##                                 0.95209005
##                           PossessionTeamMIA
##                                 0.05518131
##                           PossessionTeamMIN
##                                -0.05919540
##                            PossessionTeamNE
##                                 0.53816994
```

```
##                            PossessionTeamNO
##                                  1.69049649
##                           PossessionTeamNYG
##                                  0.81186538
##                           PossessionTeamNYJ
##                                  0.12309674
##                           PossessionTeamOAK
##                                  0.63107048
##                           PossessionTeamPHI
##                                  0.92693806
##                           PossessionTeamPIT
##                                  1.01782074
##                           PossessionTeamSEA
##                                  0.21956451
##                            PossessionTeamSF
##                                  0.52377034
##                            PossessionTeamTB
##                                  0.04561318
##                           PossessionTeamTEN
##                                  0.94384586
##                           PossessionTeamWAS
##                                 -0.05971857
##                                      Down.L
##                                 -0.63313387
##                                      Down.Q
##                                 -0.62457582
##                                      Down.C
##                                 -0.36004241
##                                    Distance
##                                  0.08398595
##                       OffenseFormationI_FORM
##                                 -0.50450769
##                        OffenseFormationJUMBO
##                                 -0.32362647
##                       OffenseFormationPISTOL
##                                 -0.49613609
##                      OffenseFormationSHOTGUN
##                                 -0.68759777
##                  OffenseFormationSINGLEBACK
##                                 -0.56554251
##                     OffenseFormationWILDCAT
##                                 -0.84658640
##           OffensePersonnel0 RB, 2 TE, 3 WR
##                                 -1.30532263
##           OffensePersonnel1 RB, 0 TE, 4 WR
##                                  3.43035544
##      OffensePersonnel1 RB, 1 TE, 2 WR,1 DB
##                                  7.76740241
##      OffensePersonnel1 RB, 1 TE, 2 WR,1 DL
##                                  1.98621204
##           OffensePersonnel1 RB, 1 TE, 3 WR
##                                  2.84005797
##      OffensePersonnel1 RB, 2 TE, 1 WR,1 DL
##                                  3.15175661
```

```
##       OffensePersonnel1 RB, 2 TE, 1 WR,1 LB
##                                  6.18902002
##            OffensePersonnel1 RB, 2 TE, 2 WR
##                                  2.67403284
##       OffensePersonnel1 RB, 3 TE, 0 WR,1 DL
##                                  2.28775612
##       OffensePersonnel1 RB, 3 TE, 0 WR,1 LB
##                                  4.29108556
##            OffensePersonnel1 RB, 3 TE, 1 WR
##                                  2.62599267
##            OffensePersonnel1 RB, 4 TE, 0 WR
##                                  2.11627955
##      OffensePersonnel2 QB, 1 RB, 0 TE, 3 WR
##                                  2.80048909
##      OffensePersonnel2 QB, 1 RB, 1 TE, 2 WR
##                                  2.66194505
##      OffensePersonnel2 QB, 1 RB, 2 TE, 1 WR
##                                  0.89022345
##      OffensePersonnel2 QB, 2 RB, 1 TE, 1 WR
##                                  6.25593404
##            OffensePersonnel2 RB, 0 TE, 3 WR
##                                  3.45922831
##            OffensePersonnel2 RB, 1 TE, 2 WR
##                                  2.73182300
##            OffensePersonnel2 RB, 2 TE, 1 WR
##                                  3.27488832
##            OffensePersonnel2 RB, 3 TE, 0 WR
##                                  1.68366195
##            OffensePersonnel3 RB, 0 TE, 2 WR
##                                  0.37120149
##            OffensePersonnel3 RB, 1 TE, 1 WR
##                                  2.41667123
##            OffensePersonnel3 RB, 2 TE, 0 WR
##                                  2.72744073
##      OffensePersonnel6 OL, 1 RB, 0 TE, 3 WR
##                                  3.08654545
## OffensePersonnel6 OL, 1 RB, 1 TE, 1 WR,1 DL
##                                  1.81618010
##      OffensePersonnel6 OL, 1 RB, 1 TE, 2 WR
##                                  2.08163968
## OffensePersonnel6 OL, 1 RB, 2 TE, 0 WR,1 DL
##                                  2.70307245
## OffensePersonnel6 OL, 1 RB, 2 TE, 0 WR,1 LB
##                                  3.88172678
##      OffensePersonnel6 OL, 1 RB, 2 TE, 1 WR
##                                  2.95695541
##      OffensePersonnel6 OL, 1 RB, 3 TE, 0 WR
##                                  3.14659273
##      OffensePersonnel6 OL, 2 RB, 0 TE, 2 WR
##                                  3.96960985
## OffensePersonnel6 OL, 2 RB, 1 TE, 0 WR,1 DL
##                                  2.17678393
##      OffensePersonnel6 OL, 2 RB, 1 TE, 1 WR
##                                  3.36070656
```

```
##      OffensePersonnel6 OL, 2 RB, 2 TE, 0 WR
##                                 3.32902917
##      OffensePersonnel7 OL, 1 RB, 0 TE, 2 WR
##                                 2.73854889
##      OffensePersonnel7 OL, 1 RB, 2 TE, 0 WR
##                                 2.67756499
##      OffensePersonnel7 OL, 2 RB, 0 TE, 1 WR
##                                 3.33216584
##                         DefendersInTheBox.L
##                                -7.32478206
##                         DefendersInTheBox.Q
##                                 2.85631790
##                         DefendersInTheBox.C
##                                -1.61679386
##                         DefendersInTheBox^4
##                                 0.93696063
##                         DefendersInTheBox^5
##                                -0.19978324
##                         DefendersInTheBox^6
##                                 0.40815457
##                         DefendersInTheBox^7
##                                -0.11597370
##                         DefendersInTheBox^8
##                                 0.25564617
##            DefensePersonnel0 DL, 5 LB, 6 DB
##                                 0.97626151
##            DefensePersonnel1 DL, 3 LB, 7 DB
##                                -0.05725731
##            DefensePersonnel1 DL, 4 LB, 6 DB
##                                 0.79085292
##            DefensePersonnel1 DL, 5 LB, 5 DB
##                                 1.32987727
##            DefensePersonnel2 DL, 2 LB, 7 DB
##                                 3.22851736
##            DefensePersonnel2 DL, 3 LB, 6 DB
##                                 2.22597056
##            DefensePersonnel2 DL, 4 LB, 5 DB
##                                 1.72382273
##            DefensePersonnel2 DL, 5 LB, 4 DB
##                                 1.25490849
##            DefensePersonnel3 DL, 1 LB, 7 DB
##                                 1.01058640
##            DefensePersonnel3 DL, 2 LB, 6 DB
##                                 2.00367702
##            DefensePersonnel3 DL, 3 LB, 5 DB
##                                 1.68305586
##            DefensePersonnel3 DL, 4 LB, 4 DB
##                                 1.87769291
##            DefensePersonnel3 DL, 5 LB, 3 DB
##                                 2.49005849
##            DefensePersonnel4 DL, 0 LB, 7 DB
##                                -1.05487035
##            DefensePersonnel4 DL, 1 LB, 6 DB
##                                 2.47192100
```

```
##            DefensePersonnel4 DL, 2 LB, 5 DB
##                                   1.74946935
##            DefensePersonnel4 DL, 3 LB, 4 DB
##                                   1.58488048
##            DefensePersonnel4 DL, 4 LB, 3 DB
##                                   0.50694608
##            DefensePersonnel4 DL, 5 LB, 2 DB
##                                   0.98642474
##            DefensePersonnel5 DL, 1 LB, 5 DB
##                                   0.84721849
##            DefensePersonnel5 DL, 2 LB, 4 DB
##                                   2.35149482
##      DefensePersonnel5 DL, 3 LB, 2 DB, 1 OL
##                                   0.19962839
##            DefensePersonnel5 DL, 3 LB, 3 DB
##                                   0.47388302
##      DefensePersonnel5 DL, 4 LB, 1 DB, 1 OL
##                                  -0.18884772
##            DefensePersonnel5 DL, 4 LB, 2 DB
##                                   0.68686377
##            DefensePersonnel5 DL, 5 LB, 1 DB
##                                  -0.24882664
##            DefensePersonnel6 DL, 2 LB, 3 DB
##                                  -0.13150646
##            DefensePersonnel6 DL, 3 LB, 2 DB
##                                   0.18396843
##            DefensePersonnel6 DL, 4 LB, 1 DB
##                                  -0.03062638
##                           PlayDirectionright
##                                  -0.03651157
##                                 PlayerHeight
##                                  -0.02456371
##                                 PlayerWeight
##                                  -0.00188710
##                                   PositionHB
##                                   1.76069692
##                                   PositionQB
##                                  -1.13566553
##                                   PositionRB
##                                   0.15926141
##                                   PositionTE
##                                   1.69615801
##                                   PositionWR
##                                   1.93246856
##                              HomeTeamAbbrATL
##                                   0.08198871
##                              HomeTeamAbbrBAL
##                                  -0.31650457
##                              HomeTeamAbbrBUF
##                                  -0.07351799
##                              HomeTeamAbbrCAR
##                                   0.15384437
##                              HomeTeamAbbrCHI
##                                  -0.88531074
```

```
##                         HomeTeamAbbrCIN
##                              0.26737373
##                         HomeTeamAbbrCLE
##                             -0.28456253
##                         HomeTeamAbbrDAL
##                              0.05802567
##                         HomeTeamAbbrDEN
##                             -0.27034530
##                         HomeTeamAbbrDET
##                             -0.51724057
##                          HomeTeamAbbrGB
##                             -0.20405597
##                         HomeTeamAbbrHOU
##                             -0.28264632
##                         HomeTeamAbbrIND
##                             -0.34272825
##                         HomeTeamAbbrJAX
##                             -0.12364225
##                          HomeTeamAbbrKC
##                             -0.29151672
##                          HomeTeamAbbrLA
##                              0.46937017
##                         HomeTeamAbbrLAC
##                              0.01047147
##                         HomeTeamAbbrMIA
##                              0.27611058
##                         HomeTeamAbbrMIN
##                             -0.50006295
##                          HomeTeamAbbrNE
##                              0.42103917
##                          HomeTeamAbbrNO
##                             -0.44120522
##                         HomeTeamAbbrNYG
##                              0.06701709
##                         HomeTeamAbbrNYJ
##                              0.43354830
##                         HomeTeamAbbrOAK
##                              0.01076283
##                         HomeTeamAbbrPHI
##                             -0.15252694
##                         HomeTeamAbbrPIT
##                             -0.24285636
##                         HomeTeamAbbrSEA
##                              0.19984037
##                          HomeTeamAbbrSF
##                             -0.23649103
##                          HomeTeamAbbrTB
##                              0.05777012
##                         HomeTeamAbbrTEN
##                              0.02166246
##                         HomeTeamAbbrWAS
##                              0.11388127
##                      VisitorTeamAbbrATL
##                              0.03318052
```

```
##                         VisitorTeamAbbrBAL
##                                -0.86663662
##                         VisitorTeamAbbrBUF
##                                 0.00772628
##                         VisitorTeamAbbrCAR
##                                 0.14640238
##                         VisitorTeamAbbrCHI
##                                -0.16795927
##                         VisitorTeamAbbrCIN
##                                -0.08809032
##                         VisitorTeamAbbrCLE
##                                 0.17526987
##                         VisitorTeamAbbrDAL
##                                -0.16115269
##                         VisitorTeamAbbrDEN
##                                 0.45728488
##                         VisitorTeamAbbrDET
##                                -0.01267271
##                          VisitorTeamAbbrGB
##                                -0.03680102
##                         VisitorTeamAbbrHOU
##                                -1.09977799
##                         VisitorTeamAbbrIND
##                                -0.23560234
##                         VisitorTeamAbbrJAX
##                                 0.49311369
##                          VisitorTeamAbbrKC
##                                 0.64711081
##                          VisitorTeamAbbrLA
##                                 0.76207938
##                         VisitorTeamAbbrLAC
##                                -0.00839654
##                         VisitorTeamAbbrMIA
##                                 0.43375656
##                         VisitorTeamAbbrMIN
##                                 0.18078730
##                          VisitorTeamAbbrNE
##                                 0.54313845
##                          VisitorTeamAbbrNO
##                                -0.29318421
##                         VisitorTeamAbbrNYG
##                                 0.06948105
##                         VisitorTeamAbbrNYJ
##                                 0.09937728
##                         VisitorTeamAbbrOAK
##                                 0.21839019
##                         VisitorTeamAbbrPHI
##                                 0.04239268
##                         VisitorTeamAbbrPIT
##                                -0.21032051
##                         VisitorTeamAbbrSEA
##                                 0.06408241
##                          VisitorTeamAbbrSF
##                                 0.40801456
```

```
##                            VisitorTeamAbbrTB
##                                   0.31857477
##                           VisitorTeamAbbrTEN
##                                  -0.12675904
##                           VisitorTeamAbbrWAS
##                                   0.54252203
##                                         Week
##                                  -0.01535966
##                                  Temperature
##                                  -0.01052696
##                                     Humidity
##                                  -0.00431358
##                              TimeDifference
##                                   0.09306539
##                           HomeScoreAdvantage
##                                  -0.00600195
##                                    PlayerAge
##                                  -0.02960855
```

```
#NFL_Train_Total_Model$coef)
#summary(NFL_Train_Total_Model)$coef[summary(NFL_Train_Total_Model)$coef[,4] <= .05, 1]
```

What if we always predicted the mean of yards? (Just Intercept Term)

```
NFL_Train_Total_Model1 = lm(Yards ~ 1, data=NFL_DATA_TRAIN_Filtered_Final)
NFL_Train_Total_Model1.cv = cvFit(NFL_Train_Total_Model1, data=NFL_DATA_TRAIN_Filtered_Final, y=NFL_DATA
NFL_Train_Total_Model1.cv # RMSE= 6.4191
```

```
## 10-fold CV results:
##     CV
## 6.4304
```

Forward Stepwise Regression

```
min_model = NFL_Train_Total_Model1
max_model = NFL_Train_Total_Model
stepwise_model = step(min_model, direction='forward', scope=max_model)
```

```
## Start:  AIC=62211
## Yards ~ 1
```

```
summary(stepwise_model)
```

```
##
## Call:
## lm(formula = Yards ~ 1, data = NFL_DATA_TRAIN_Filtered_Final)
##
## Residuals:
##    Min     1Q Median     3Q    Max
##  -18.2   -3.2   -1.2    1.8   94.8
```

```
##
## Coefficients:
##             Estimate Std. Error t value            Pr(>|t|)
## (Intercept)   4.1974     0.0497    84.4 <0.0000000000000002 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 6.43 on 16713 degrees of freedom
```

```
# Ultimately, this is saying that the extra info we gain is not worth the complexity
```

Backward Stepwise Regerssion

```
backward_step = step(max_model, direction='backward')
backward_step
```

```
summary(backward_step)
```

```
##
## Call:
## lm(formula = Yards ~ Season + GameClock + Distance + DefendersInTheBox +
##     PlayerHeight + Position + Temperature + HomeScoreAdvantage +
##     PlayerAge, data = NFL_DATA_TRAIN_Filtered_Final)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -19.54  -3.15  -1.18   1.32  94.57
##
## Coefficients:
##                      Estimate Std. Error t value         Pr(>|t|)
## (Intercept)          8.110000   2.203312    3.68          0.00023 ***
## Season2018           0.306328   0.099802    3.07          0.00215 **
## GameClock            0.000526   0.000188    2.79          0.00521 **
## Distance             0.078724   0.013740    5.73 0.00000001024767 ***
## DefendersInTheBox.L -7.732176   1.070072   -7.23 0.00000000000052 ***
## DefendersInTheBox.Q  1.745432   1.036363    1.68          0.09216 .
## DefendersInTheBox.C -1.411945   0.896918   -1.57          0.11546
## DefendersInTheBox^4  0.706433   0.736744    0.96          0.33764
## DefendersInTheBox^5  0.279722   0.577483    0.48          0.62812
## DefendersInTheBox^6  0.556270   0.427169    1.30          0.19286
## DefendersInTheBox^7  0.043472   0.280617    0.15          0.87689
## DefendersInTheBox^8  0.311971   0.145645    2.14          0.03221 *
## PlayerHeight        -0.041499   0.027849   -1.49          0.13620
## PositionHB           0.102257   0.660893    0.15          0.87704
## PositionQB          -0.974017   1.042221   -0.93          0.35003
## PositionRB           0.147750   0.585328    0.25          0.80072
## PositionTE           1.694155   1.481742    1.14          0.25291
## PositionWR           1.746851   0.657730    2.66          0.00792 **
## Temperature         -0.007202   0.002829   -2.55          0.01092 *
## HomeScoreAdvantage  -0.007435   0.004602   -1.62          0.10618
## PlayerAge           -0.050160   0.016400   -3.06          0.00223 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##
## Residual standard error: 6.37 on 16693 degrees of freedom
## Multiple R-squared:  0.0205, Adjusted R-squared:  0.0193
## F-statistic: 17.4 on 20 and 16693 DF,  p-value: <0.0000000000000002
```

correction

```
pvals <- summary(backward_step)$coefficients[,'Pr(>|t|)']
n_significant = 13
n_covariates = 24
```

```
cat("Bonferroni Corection: \n")
```

```
## Bonferroni Corection:
```

```
p.adjust(pvals, method = 'bonferroni', n = n_significant + n_covariates + 1)
```

```
##         (Intercept)          Season2018           GameClock
##   0.008862146043535   0.081649268785298   0.198035839299143
##            Distance DefendersInTheBox.L DefendersInTheBox.Q
##   0.000000389411565   0.000000000019742   1.000000000000000
## DefendersInTheBox.C DefendersInTheBox^4 DefendersInTheBox^5
##   1.000000000000000   1.000000000000000   1.000000000000000
## DefendersInTheBox^6 DefendersInTheBox^7 DefendersInTheBox^8
##   1.000000000000000   1.000000000000000   1.000000000000000
##        PlayerHeight          PositionHB          PositionQB
##   1.000000000000000   1.000000000000000   1.000000000000000
##          PositionRB          PositionTE          PositionWR
##   1.000000000000000   1.000000000000000   0.300872162062431
##         Temperature  HomeScoreAdvantage           PlayerAge
##   0.414900546828430   1.000000000000000   0.084629037841733
```

```
cat("Benjamini-Hochberg: \n")
```

```
## Benjamini-Hochberg:
```

```
bh <- p.adjust(pvals, method = 'BH', n = n_significant + n_covariates +1)
bh
```

```
##         (Intercept)          Season2018           GameClock
##   0.002954048681178   0.016925807568347   0.033005973216524
##            Distance DefendersInTheBox.L DefendersInTheBox.Q
##   0.000000194705783   0.000000000019742   0.350222460842332
## DefendersInTheBox.C DefendersInTheBox^4 DefendersInTheBox^5
##   0.365610766419858   0.782418248625900   1.000000000000000
## DefendersInTheBox^6 DefendersInTheBox^7 DefendersInTheBox^8
##   0.523471072141957   1.000000000000000   0.135989827319851
##        PlayerHeight          PositionHB          PositionQB
##   0.398117387374248   1.000000000000000   0.782418248625900
##          PositionRB          PositionTE          PositionWR
##   1.000000000000000   0.640700707715220   0.042981737437490
##         Temperature  HomeScoreAdvantage           PlayerAge
##   0.051862568353554   0.365610766419858   0.016925807568347
```

```r
which(bh < 0.05)
```

```
##         (Intercept)          Season2018           GameClock
##                   1                   2                   3
##            Distance DefendersInTheBox.L          PositionWR
##                   4                   5                  18
##           PlayerAge
##                  21
```

```r
backward_step.cv = cvFit(backward_step, data=NFL_DATA_TRAIN_Filtered_Final, y=NFL_DATA_TRAIN_Filtered_Fi
backward_step.cv # RMSE= 6.5386 # Best Model so far
```

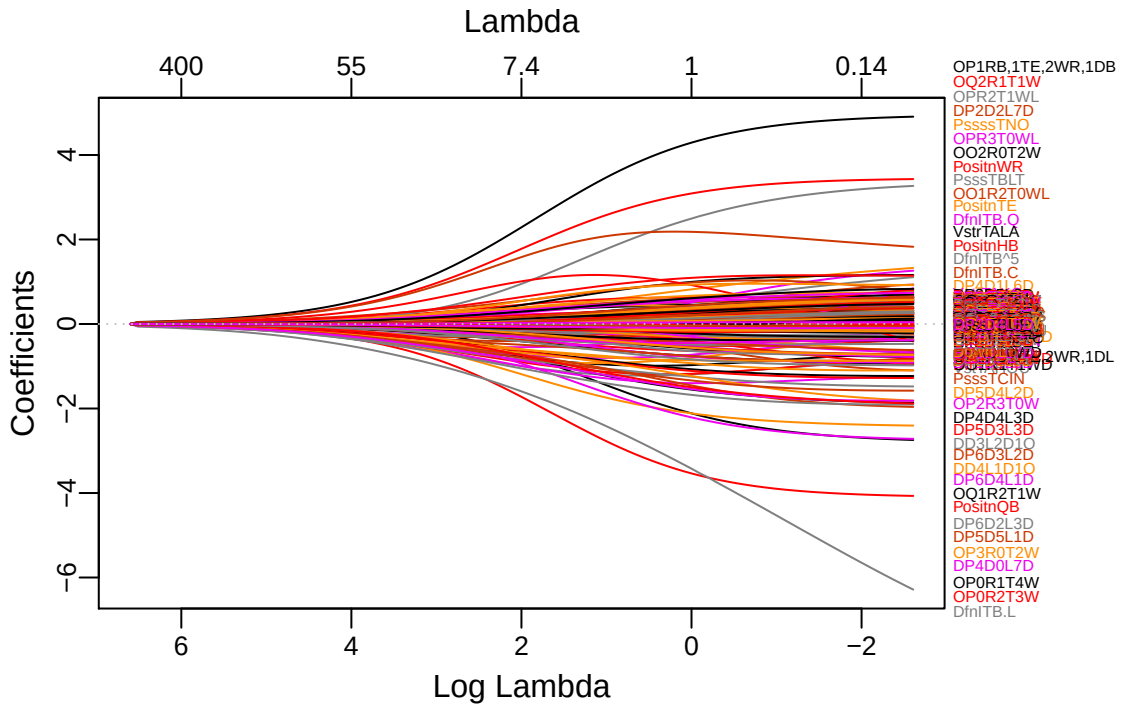
```
## 10-fold CV results:
##     CV
## 6.3744
```

Ridge Regression

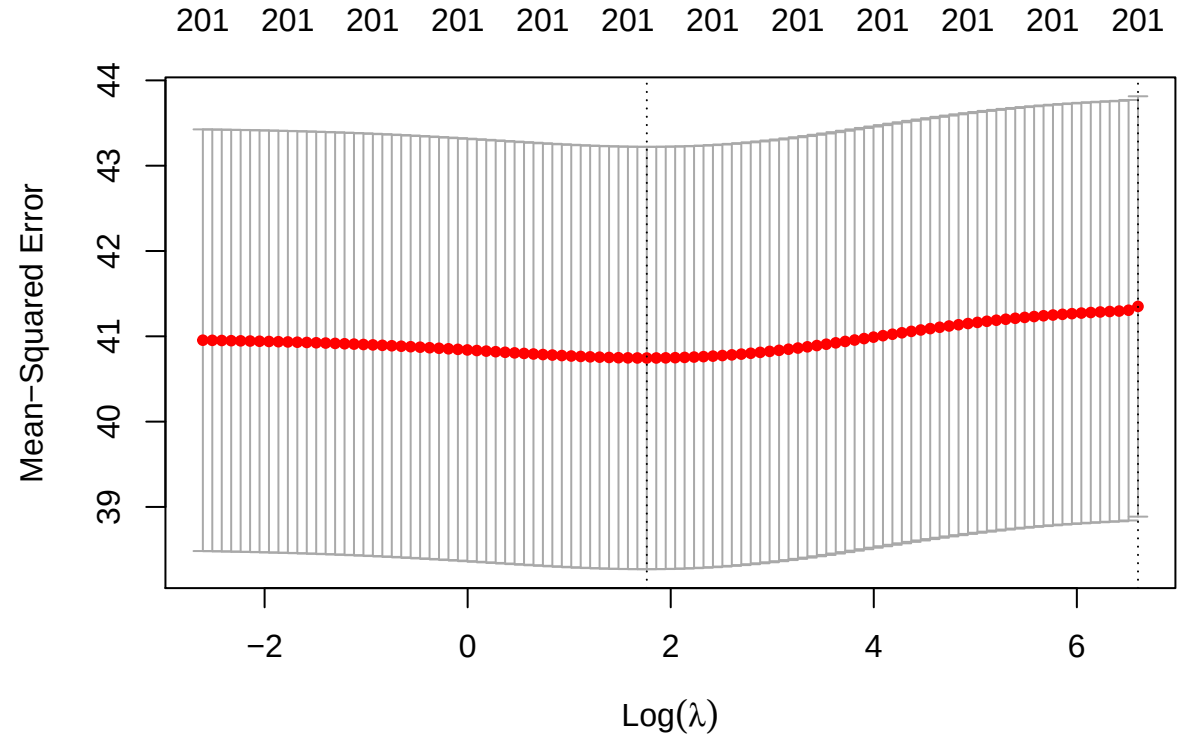
```r
library(glmnet)
## NORMALIZE Continouous Covariates
Standardized_NFL_TRAIN = NFL_DATA_TRAIN_Filtered_Final
Standardized_NFL_TRAIN$X = scale(Standardized_NFL_TRAIN$X)
Standardized_NFL_TRAIN$Y = scale(Standardized_NFL_TRAIN$Y)
Standardized_NFL_TRAIN$GameClock = scale(Standardized_NFL_TRAIN$GameClock )
Standardized_NFL_TRAIN$Distance = scale(Standardized_NFL_TRAIN$Distance)
Standardized_NFL_TRAIN$PlayerHeight = scale(Standardized_NFL_TRAIN$PlayerHeight)
Standardized_NFL_TRAIN$PlayerWeight = scale(Standardized_NFL_TRAIN$PlayerWeight)
Standardized_NFL_TRAIN$Week = scale(Standardized_NFL_TRAIN$Week)
Standardized_NFL_TRAIN$Temperature = scale(Standardized_NFL_TRAIN$Temperature)
Standardized_NFL_TRAIN$Humidity = scale(Standardized_NFL_TRAIN$Humidity)
Standardized_NFL_TRAIN$TimeDifference = scale(Standardized_NFL_TRAIN$TimeDifference)
Standardized_NFL_TRAIN$HomeScoreAdvantage = scale(Standardized_NFL_TRAIN$HomeScoreAdvantage )
Standardized_NFL_TRAIN$PlayerAge = scale(Standardized_NFL_TRAIN$PlayerAge)

# Ridge Regression
# Ridge alpha = 0
x = model.matrix(Yards~. , Standardized_NFL_TRAIN)
y = Standardized_NFL_TRAIN$Yards
ridge_mod = glmnet(x, y, alpha = 0)
# install.packages("plotmo")
plot_glmnet(ridge_mod, label = TRUE)
```

```
## Warning in TeachingDemos::spread.labs(beta[iname, ncol(beta)], mindiff =
## 1.2 * : Maximum iterations reached
```




```
cvfit = cv.glmnet(x, y, alpha = 0)
plot(cvfit)
```




```
bestlam = cvfit$lambda.min # = 4.9384
```

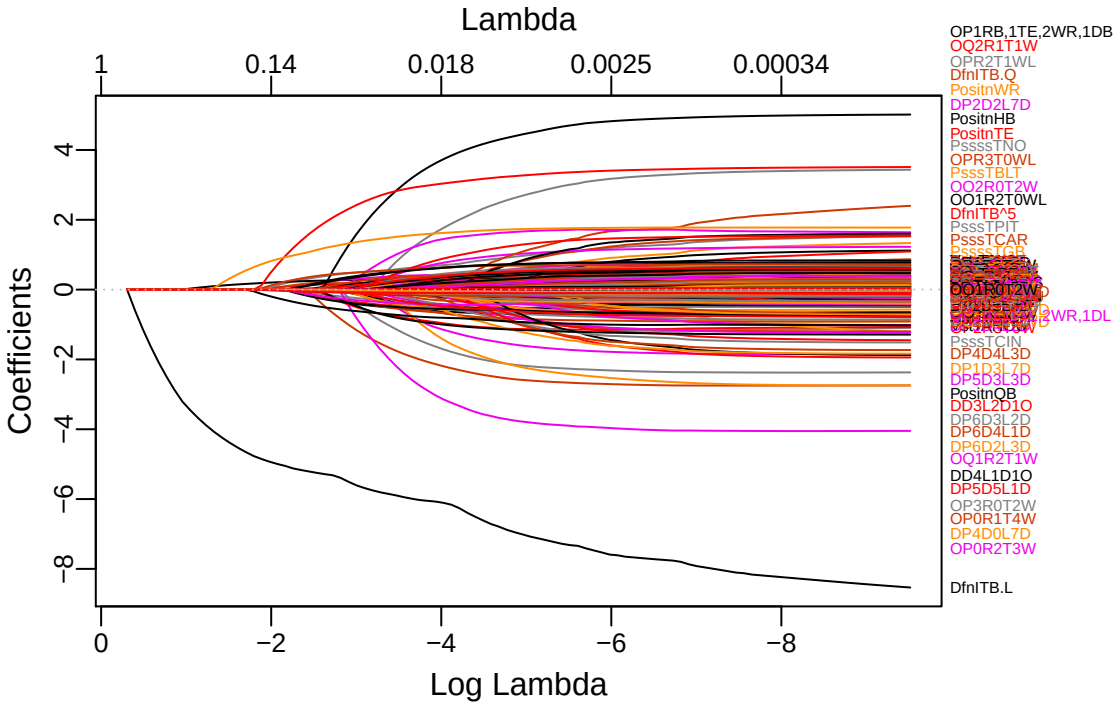
Get coefficients when log lamda is 10.098

```
y_predicted <- predict(cvfit, s = bestlam, newx = x) # same x, in sample prediction
ridge_RMSE = sqrt(mean((y_predicted - y)^2))
# ridge_RMSE # = 6.3333
#coef(ridge_mod)[,4.9384] # Best is again basically forcing all the betas to 0. Just predict mean
```

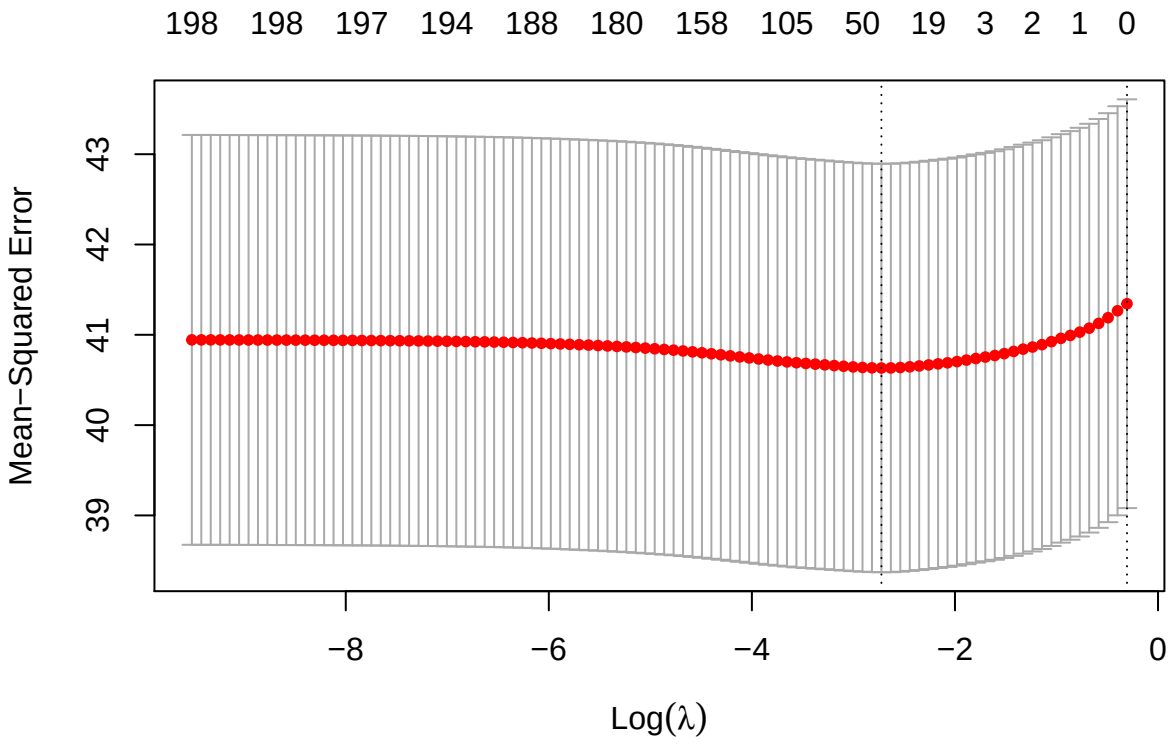
Lasso Regression

```
lasso_mod= glmnet(x, y, alpha = 1)
# coef(lasso_mod)[,50]
plot_glmnet(lasso_mod, label = TRUE)
```

```
## Warning in TeachingDemos::spread.labs(beta[iname, ncol(beta)], mindiff =
## 1.2 * : Maximum iterations reached
```




```
cvfit_lasso = cv.glmnet(x, y, alpha = 1)
plot(cvfit_lasso)
```




```
bestlam_lasso = cvfit_lasso$lambda.min # = 0.046056
```

```
y_predicted_lasso <- predict(cvfit_lasso, s = bestlam_lasso, newx = x) # same x, in sample prediction
lasso_RMSE = sqrt(mean((y_predicted_lasso - y)^2))
lasso_RMSE # = 6.3349
```

```
## [1] 6.3578
```

```
out = glmnet(x, y, alpha = 1) # Fit ridge regression model on full dataset
#predict(out, type = "coefficients", s = bestlam_lasso)[1:80,] # Display coefficients using lambda chos
```

#Applying same transformation to test set

```
# Function to take the difference in time from the dataframe
timeDifference <- function(time) {
  num <- gsub("[:]", "" , str_sub(time, 12, 19), perl=TRUE)
  hr <- ifelse(str_sub(num, 1, 2) == "00", 24, as.numeric(str_sub(num, 1, 2)))
  min <- as.numeric(str_sub(num, 3, 4))
  sec <- as.numeric(str_sub(num, 5, 6))
  newTime <- 3600*hr + 60 * min + sec
  return(newTime)
}
# Add Time_Difference between the snap and the handoff
NFL_DATA_Holdout$TimeDifference <-
  timeDifference(NFL_DATA_Holdout$TimeHandoff) - timeDifference(NFL_DATA_Holdout$TimeSnap)

# Add the Difference in Score by home score - visitor score
# Difference in Score (Pair with which team is winning (HomeScore-AwayScore))
NFL_DATA_Holdout$HomeScoreAdvantage <-
  NFL_DATA_Holdout$HomeScoreBeforePlay - NFL_DATA_Holdout$VisitorScoreBeforePlay

# Add the age of the running player
```

```
# Change the birth dates to strings
NFL_DATA_Holdout$PlayerBirthDate = as.character(NFL_DATA_Holdout$PlayerBirthDate)
# Grab the Year for each of the running player
Birth_Year = str_sub(NFL_DATA_Holdout$PlayerBirthDate, 7, 11)
# Grab Month of each running player
Birth_Month = str_sub(NFL_DATA_Holdout$PlayerBirthDate, 1, 2)
# If Born in July (07) Have lived 5/12 of a year. ie (12 - (Birth_Month)) / 12
How_Much_Of_Year_Lived = (12 - as.numeric(Birth_Month)) / 12
Years_Lived = NFL_DATA_Holdout$Season - as.numeric(Birth_Year)
Total_Years_Lived = Years_Lived + How_Much_Of_Year_Lived
NFL_DATA_Holdout$PlayerAge = Total_Years_Lived

# Change HEIGHT to inches and continuous
Feet = as.numeric(str_sub(NFL_DATA_Holdout$PlayerHeight, 1, 1))
Inches = as.numeric(str_sub(NFL_DATA_Holdout$PlayerHeight, 3, 4))
Heights = (Feet * 12) + Inches
NFL_DATA_Holdout$PlayerHeight = Heights

# Changes GAMECLOCK to Seconds.

NFL_DATA_Holdout$GameClock = as.numeric(NFL_DATA_Holdout$GameClock)

# FACTORING VARIABLES INTO CATEGORICAL

# Factor OFFENSE FORMATION
NFL_DATA_Holdout$OffenseFormation = factor(NFL_DATA_Holdout$OffenseFormation)

# DEFENDERS IN BOX (Need Categorical and Ordinal)
NFL_DATA_Holdout$DefendersInTheBox = factor(NFL_DATA_Holdout$DefendersInTheBox)


# REFACTOR DEFENDER IN BOX TO INCLUDE ORDINALITY
# Leaving them unordered was for graphs above, to look good
NFL_DATA_Holdout$DefendersInTheBox = factor(NFL_DATA_Holdout$DefendersInTheBox, order = TRUE, levels= c

# Need to count how many NA / Empty cells there are for each column
# summary(NFL_DATA_TRAIN_Filtered)  # changed empty to NA when reading in file
# GameWeather, Temperature, Humidy all have missing or NA data
# sum(is.na(NFL_DATA_TRAIN_Filtered$GameWeather))
# sum(NFL_DATA_TRAIN_Filtered$GameWeather == "")

# Factor the DOWNS, Ordinally
NFL_DATA_Holdout$Down = factor(as.numeric(NFL_DATA_Holdout$Down), order = TRUE, levels = c(1,2,3,4,5))

# Player WEIGHT
NFL_DATA_Holdout$PlayerWeight = as.numeric(NFL_DATA_Holdout$PlayerWeight)

# Factor POoldout
#NFL_DATA_Holdout$Position = factor(NFL_DATA_Holdout$Positoldout# factor POSITION
NFL_DATA_Holdout$Position = factor(NFL_DATA_Holdout$Position)

# factor SEASON
NFL_DATA_Holdout$Season = factor(NFL_DATA_Holdout$Season)
```

```
# DATA CLEANING (REMOVING NA'S, and observations that happen less than 3 times)
# This was causing issues where one fold has a factor but another fold does not

# Need to delete a row within a column if there is just 1 special case. (Minimun 3 observations)

# DefensePersonnel (reduces observations by 11)
NFL_DATA_Holdout = NFL_DATA_Holdout[unsplit(table(NFL_DATA_Holdout$DefensePersonnel), NFL_DATA_Holdout$

# Same for OffensePersonnel (reduces by 18 observations)
NFL_DATA_Holdout = NFL_DATA_Holdout[unsplit(table(NFL_DATA_Holdout$OffensePersonnel), NFL_DATA_Holdout$

# Same for Pooldout
NFL_DATA_Holdout = NFL_DATA_Holdout[unsplit(table(NFL_DATA_Holdout$Position), NFL_DATA_Holdout$Position

# Same for Defenders In the Box
NFL_DATA_Holdout = NFL_DATA_Holdout[unsplit(table(NFL_DATA_Holdout$DefendersInTheBox), NFL_DATA_Holdout

# Same for Offense Formation
NFL_DATA_Holdout = NFL_DATA_Holdout[unsplit(table(NFL_DATA_Holdout$OffenseFormation), NFL_DATA_Holdout$



# Drop columns that are collinear, or we think are not critical to our model
NFL_DATA_Holdout = select(NFL_DATA_Holdout,
                                -GameId, -PlayId, -Team, -S, -A, -Dis,
                                -Orientation, -Dir, -DisplayName, -JerseyNumber,
                                -YardLine, -FieldPosition, -HomeScoreBeforePlay,
                                -VisitorScoreBeforePlay, -NflId, -TimeHandoff,
                                -TimeSnap, -PlayerBirthDate, -PlayerCollegeName,
                                -Location,-WindSpeed, -WindDirection, -StadiumType,
                                -Turf,-GameWeather,-NflIdRusher, -Stadium)
# Turf and stadium type all captured in stadium
# drop game weather, captured in Week, and Stadium. Also too many missing values

NFL_DATA_HOLDOUT_Final <- na.omit(NFL_DATA_Holdout)

View(NFL_DATA_HOLDOUT_Final)
```

```
## Warning in system2("/usr/bin/otool", c("-L", shQuote(DSO)), stdout = TRUE):
## running command ''/usr/bin/otool' -L '/Library/Frameworks/R.framework/
## Resources/modules/R_de.so'' had status 1
```

Using model with all covariates to predict on test set

```
NFL_TEST_Model.cv = cvFit(NFL_Train_Total_Model, data=NFL_DATA_HOLDOUT_Final, y=NFL_DATA_HOLDOUT_Final$
```

```
## Warning in predict.lm(...): prediction from a rank-deficient fit may be
## misleading
```

```
NFL_TEST_Model.cv # RMSE= 6.4191
```

```
## 10-fold CV results:
##     CV
## 6.7821
```

```
#pred = predict(NFL_Train_Total_Model, NFL_DATA_HOLDOUT_Final)
#rmse.test = sqrt(mean((pred - NFL_DATA_HOLDOUT_Final$Yards)^2))
#rmse.test
```

Using model with only intercept term

```
NFL_TEST_Model.cv = cvFit(NFL_Train_Total_Model1, data=NFL_DATA_HOLDOUT_Final, y=NFL_DATA_HOLDOUT_Final$
NFL_TEST_Model.cv # RMSE= 6.4191
```

```
## 10-fold CV results:
##     CV
## 6.6685
```

#Using 'best' model (backward stepwise regression)

```
NFL_TEST_Model.cv = cvFit(backward_step, data=NFL_DATA_HOLDOUT_Final, y=NFL_DATA_HOLDOUT_Final$Yards, K=
NFL_TEST_Model.cv # RMSE= 6.4191
```

```
## 10-fold CV results:
##     CV
## 6.6491
```

```
summary(backward_step)
```

```
##
## Call:
## lm(formula = Yards ~ Season + GameClock + Distance + DefendersInTheBox +
##     PlayerHeight + Position + Temperature + HomeScoreAdvantage +
##     PlayerAge, data = NFL_DATA_TRAIN_Filtered_Final)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -19.54  -3.15  -1.18   1.32  94.57
##
## Coefficients:
##                       Estimate Std. Error t value         Pr(>|t|)
## (Intercept)           8.110000   2.203312    3.68          0.00023 ***
## Season2018            0.306328   0.099802    3.07          0.00215 **
## GameClock             0.000526   0.000188    2.79          0.00521 **
## Distance              0.078724   0.013740    5.73 0.00000001024767 ***
## DefendersInTheBox.L -7.732176   1.070072   -7.23 0.00000000000052 ***
## DefendersInTheBox.Q  1.745432   1.036363    1.68          0.09216 .
## DefendersInTheBox.C -1.411945   0.896918   -1.57          0.11546
## DefendersInTheBox^4  0.706433   0.736744    0.96          0.33764
## DefendersInTheBox^5  0.279722   0.577483    0.48          0.62812
## DefendersInTheBox^6  0.556270   0.427169    1.30          0.19286
## DefendersInTheBox^7  0.043472   0.280617    0.15          0.87689
## DefendersInTheBox^8  0.311971   0.145645    2.14          0.03221 *
## PlayerHeight        -0.041499   0.027849   -1.49          0.13620
## PositionHB           0.102257   0.660893    0.15          0.87704
```

```
## PositionQB          -0.974017   1.042221   -0.93          0.35003
## PositionRB           0.147750   0.585328    0.25          0.80072
## PositionTE           1.694155   1.481742    1.14          0.25291
## PositionWR           1.746851   0.657730    2.66          0.00792 **
## Temperature         -0.007202   0.002829   -2.55          0.01092 *
## HomeScoreAdvantage  -0.007435   0.004602   -1.62          0.10618
## PlayerAge           -0.050160   0.016400   -3.06          0.00223 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 6.37 on 16693 degrees of freedom
## Multiple R-squared:  0.0205, Adjusted R-squared:  0.0193
## F-statistic: 17.4 on 20 and 16693 DF,  p-value: <0.0000000000000002
```

Fitting Backward Stepwise Regression to test set

```
#NFL_TEST_min_Model = lm(Yards ~ 1, data=NFL_DATA_HOLDOUT_Final)
NFL_TEST_max_Model = lm(Yards ~ ., data=NFL_DATA_HOLDOUT_Final)
test_backward_step = step(NFL_TEST_max_Model, direction='backward')
```

```
## Start:  AIC=16034
## Yards ~ X + Y + Season + Quarter + GameClock + PossessionTeam +
##     Down + Distance + OffenseFormation + OffensePersonnel + DefendersInTheBox +
##     DefensePersonnel + PlayDirection + PlayerHeight + PlayerWeight +
##     Position + HomeTeamAbbr + VisitorTeamAbbr + Week + Temperature +
##     Humidity + TimeDifference + HomeScoreAdvantage + PlayerAge
##
##                      Df Sum of Sq    RSS   AIC
## - HomeTeamAbbr       31      1216 177364 16001
## - DefensePersonnel   22       571 176718 16003
## - VisitorTeamAbbr    31      1483 177630 16007
## - OffensePersonnel   25      1181 177328 16012
## - PossessionTeam     31      2162 178309 16023
## - OffenseFormation    6       131 176278 16025
## - Down                3       110 176257 16030
## - PlayerHeight        1         0 176147 16032
## - Y                   1         1 176148 16032
## - Season              1         1 176148 16032
## - Temperature         1        17 176164 16032
## - Week                1        19 176166 16032
## - PlayDirection       1        19 176166 16032
## - X                   1        33 176180 16033
## - PlayerWeight        1        44 176191 16033
## - GameClock           1        48 176195 16033
## - HomeScoreAdvantage  1        61 176208 16033
## - Distance            1        68 176215 16033
## - Humidity            1        70 176217 16033
## <none>                           176147 16034
## - TimeDifference      1       175 176322 16036
## - DefendersInTheBox   8       781 176928 16036
## - Quarter             1       241 176388 16038
## - PlayerAge           1       243 176390 16038
```

```
## - Position            6       695 176842 16038
##
## Step:  AIC=16001
## Yards ~ X + Y + Season + Quarter + GameClock + PossessionTeam +
##     Down + Distance + OffenseFormation + OffensePersonnel + DefendersInTheBox +
##     DefensePersonnel + PlayDirection + PlayerHeight + PlayerWeight +
##     Position + VisitorTeamAbbr + Week + Temperature + Humidity +
##     TimeDifference + HomeScoreAdvantage + PlayerAge
##
##                      Df Sum of Sq    RSS   AIC
## - DefensePersonnel   22       765 178129 15975
## - VisitorTeamAbbr    31      1649 179012 15977
## - OffensePersonnel   25      1165 178529 15978
## - OffenseFormation    6       132 177495 15992
## - PossessionTeam     31      2281 179645 15992
## - Down                3       127 177491 15998
## - Y                   1         0 177364 15999
## - PlayerHeight        1         0 177364 15999
## - Temperature         1         1 177364 15999
## - Season              1         2 177366 15999
## - PlayDirection       1        16 177379 15999
## - Humidity            1        17 177381 15999
## - HomeScoreAdvantage  1        31 177395 15999
## - X                   1        33 177396 15999
## - GameClock           1        45 177408 16000
## - Week                1        46 177410 16000
## - PlayerWeight        1        49 177412 16000
## - Distance            1        84 177447 16001
## <none>                           177364 16001
## - TimeDifference      1       185 177548 16003
## - DefendersInTheBox   8       793 178157 16003
## - Quarter             1       201 177565 16003
## - PlayerAge           1       251 177615 16005
## - Position            6       706 178070 16005
##
## Step:  AIC=15975
## Yards ~ X + Y + Season + Quarter + GameClock + PossessionTeam +
##     Down + Distance + OffenseFormation + OffensePersonnel + DefendersInTheBox +
##     PlayDirection + PlayerHeight + PlayerWeight + Position +
##     VisitorTeamAbbr + Week + Temperature + Humidity + TimeDifference +
##     HomeScoreAdvantage + PlayerAge
##
##                      Df Sum of Sq    RSS   AIC
## - VisitorTeamAbbr    31      1549 179678 15949
## - OffensePersonnel   25      1109 179238 15951
## - PossessionTeam     31      2211 180340 15964
## - OffenseFormation    6       131 178260 15966
## - Down                3       116 178245 15971
## - Y                   1         0 178129 15973
## - PlayerHeight        1         1 178129 15973
## - Season              1         3 178132 15973
## - Temperature         1         4 178133 15973
## - Humidity            1         8 178137 15973
## - PlayDirection       1        19 178148 15973
```

```
## - X                   1        32 178161 15973
## - Week                1        36 178165 15974
## - HomeScoreAdvantage  1        39 178168 15974
## - GameClock           1        51 178180 15974
## - PlayerWeight        1        51 178180 15974
## <none>                           178129 15975
## - Distance            1        86 178215 15975
## - TimeDifference      1       193 178322 15977
## - Quarter             1       203 178332 15977
## - PlayerAge           1       266 178395 15979
## - Position            6       745 178874 15980
## - DefendersInTheBox   8      1084 179213 15984
##
## Step:  AIC=15949
## Yards ~ X + Y + Season + Quarter + GameClock + PossessionTeam +
##     Down + Distance + OffenseFormation + OffensePersonnel + DefendersInTheBox +
##     PlayDirection + PlayerHeight + PlayerWeight + Position +
##     Week + Temperature + Humidity + TimeDifference + HomeScoreAdvantage +
##     PlayerAge
##
##                       Df Sum of Sq    RSS   AIC
## - OffensePersonnel   25      1088 180766 15924
## - PossessionTeam     31      1635 181313 15925
## - OffenseFormation    6       135 179813 15940
## - Down                3       137 179815 15946
## - PlayerHeight        1         0 179678 15947
## - Y                   1         1 179679 15947
## - Temperature         1         2 179680 15947
## - Season              1         4 179682 15947
## - Humidity            1         7 179686 15947
## - PlayDirection       1        16 179695 15947
## - X                   1        29 179707 15948
## - Week                1        32 179710 15948
## - GameClock           1        55 179734 15948
## - PlayerWeight        1        58 179736 15948
## - HomeScoreAdvantage  1        72 179750 15949
## - Distance            1        85 179764 15949
## <none>                           179678 15949
## - Quarter             1       195 179873 15952
## - TimeDifference      1       207 179885 15952
## - PlayerAge           1       271 179949 15953
## - Position            6       745 180423 15954
## - DefendersInTheBox   8      1084 180762 15958
##
## Step:  AIC=15924
## Yards ~ X + Y + Season + Quarter + GameClock + PossessionTeam +
##     Down + Distance + OffenseFormation + DefendersInTheBox +
##     PlayDirection + PlayerHeight + PlayerWeight + Position +
##     Week + Temperature + Humidity + TimeDifference + HomeScoreAdvantage +
##     PlayerAge
##
##                       Df Sum of Sq    RSS   AIC
## - PossessionTeam     31      1935 182701 15907
## - OffenseFormation    6        39 180805 15913
```

```
## - Down                3       114 180880 15921
## - Y                   1         0 180766 15922
## - PlayerHeight        1         1 180767 15922
## - Temperature         1         2 180768 15922
## - Humidity            1         4 180770 15922
## - Season              1         8 180774 15923
## - PlayDirection       1        15 180781 15923
## - Week                1        28 180794 15923
## - X                   1        31 180797 15923
## - GameClock           1        45 180811 15923
## - PlayerWeight        1        51 180817 15923
## - HomeScoreAdvantage  1        57 180823 15924
## - Distance            1        85 180851 15924
## <none>                           180766 15924
## - Position            6       558 181324 15925
## - Quarter             1       170 180936 15926
## - TimeDifference      1       209 180975 15927
## - PlayerAge           1       265 181031 15928
## - DefendersInTheBox   8      1204 181970 15936
##
## Step:  AIC=15907
## Yards ~ X + Y + Season + Quarter + GameClock + Down + Distance +
##     OffenseFormation + DefendersInTheBox + PlayDirection + PlayerHeight +
##     PlayerWeight + Position + Week + Temperature + Humidity +
##     TimeDifference + HomeScoreAdvantage + PlayerAge
##
##                      Df Sum of Sq    RSS   AIC
## - OffenseFormation    6        56 182757 15896
## - Down                3        98 182799 15903
## - Position            6       362 183063 15903
## - Y                   1         0 182701 15905
## - PlayerHeight        1         0 182701 15905
## - Temperature         1        15 182716 15905
## - Week                1        18 182719 15905
## - Season              1        25 182726 15906
## - PlayDirection       1        26 182727 15906
## - PlayerWeight        1        27 182728 15906
## - Humidity            1        32 182733 15906
## - GameClock           1        37 182738 15906
## - X                   1        39 182740 15906
## - HomeScoreAdvantage  1        63 182764 15906
## <none>                           182701 15907
## - Distance            1        93 182794 15907
## - TimeDifference      1       181 182882 15909
## - Quarter             1       185 182886 15909
## - PlayerAge           1       237 182938 15910
## - DefendersInTheBox   8      1138 183839 15917
##
## Step:  AIC=15896
## Yards ~ X + Y + Season + Quarter + GameClock + Down + Distance +
##     DefendersInTheBox + PlayDirection + PlayerHeight + PlayerWeight +
##     Position + Week + Temperature + Humidity + TimeDifference +
##     HomeScoreAdvantage + PlayerAge
##
```

```
##                       Df Sum of Sq    RSS   AIC
## - Position             6       355 183111 15892
## - Down                 3        99 182856 15893
## - Y                    1         0 182757 15894
## - PlayerHeight         1         1 182758 15894
## - Temperature          1        15 182771 15895
## - Week                 1        19 182776 15895
## - PlayerWeight         1        22 182779 15895
## - Season               1        24 182780 15895
## - PlayDirection        1        25 182782 15895
## - Humidity             1        33 182790 15895
## - GameClock            1        36 182793 15895
## - X                    1        37 182794 15895
## - HomeScoreAdvantage   1        65 182821 15896
## <none>                             182757 15896
## - Distance             1        98 182855 15897
## - Quarter              1       180 182936 15898
## - TimeDifference       1       199 182956 15899
## - PlayerAge            1       232 182988 15900
## - DefendersInTheBox    8      1534 184291 15915
##
## Step:  AIC=15892
## Yards ~ X + Y + Season + Quarter + GameClock + Down + Distance +
##     DefendersInTheBox + PlayDirection + PlayerHeight + PlayerWeight +
##     Week + Temperature + Humidity + TimeDifference + HomeScoreAdvantage +
##     PlayerAge
##
##                       Df Sum of Sq    RSS   AIC
## - Down                 3       108 183219 15889
## - Y                    1         1 183113 15890
## - PlayerWeight         1         4 183116 15890
## - Temperature          1        13 183125 15891
## - PlayerHeight         1        20 183131 15891
## - PlayDirection        1        23 183134 15891
## - Season               1        24 183136 15891
## - Week                 1        26 183137 15891
## - Humidity             1        31 183142 15891
## - GameClock            1        31 183142 15891
## - X                    1        32 183143 15891
## - HomeScoreAdvantage   1        67 183179 15892
## <none>                             183111 15892
## - Distance             1       100 183211 15893
## - Quarter              1       162 183273 15894
## - TimeDifference       1       209 183320 15895
## - PlayerAge            1       211 183323 15895
## - DefendersInTheBox    8      1532 184644 15911
##
## Step:  AIC=15889
## Yards ~ X + Y + Season + Quarter + GameClock + Distance + DefendersInTheBox +
##     PlayDirection + PlayerHeight + PlayerWeight + Week + Temperature +
##     Humidity + TimeDifference + HomeScoreAdvantage + PlayerAge
##
##                       Df Sum of Sq    RSS   AIC
## - Y                    1         2 183221 15887
```

```
## - PlayerWeight        1         4 183224 15887
## - Temperature         1        16 183235 15887
## - PlayerHeight        1        21 183240 15887
## - Season              1        22 183241 15887
## - PlayDirection       1        23 183243 15887
## - Week                1        26 183245 15887
## - Humidity            1        30 183250 15888
## - X                   1        31 183251 15888
## - GameClock           1        32 183251 15888
## - HomeScoreAdvantage  1        65 183284 15888
## <none>                           183219 15889
## - Distance            1        88 183308 15889
## - Quarter             1       165 183384 15891
## - PlayerAge           1       204 183423 15892
## - TimeDifference      1       214 183434 15892
## - DefendersInTheBox   8      1679 184898 15911
##
## Step:  AIC=15887
## Yards ~ X + Season + Quarter + GameClock + Distance + DefendersInTheBox +
##     PlayDirection + PlayerHeight + PlayerWeight + Week + Temperature +
##     Humidity + TimeDifference + HomeScoreAdvantage + PlayerAge
##
##                      Df Sum of Sq    RSS   AIC
## - PlayerWeight        1         4 183225 15885
## - Temperature         1        16 183237 15885
## - PlayerHeight        1        21 183242 15885
## - Season              1        21 183243 15885
## - PlayDirection       1        24 183245 15885
## - Week                1        26 183247 15885
## - Humidity            1        30 183251 15886
## - GameClock           1        31 183253 15886
## - X                   1        32 183253 15886
## - HomeScoreAdvantage  1        65 183286 15886
## <none>                           183221 15887
## - Distance            1        88 183309 15887
## - Quarter             1       166 183387 15889
## - PlayerAge           1       204 183425 15890
## - TimeDifference      1       215 183436 15890
## - DefendersInTheBox   8      1680 184902 15909
##
## Step:  AIC=15885
## Yards ~ X + Season + Quarter + GameClock + Distance + DefendersInTheBox +
##     PlayDirection + PlayerHeight + Week + Temperature + Humidity +
##     TimeDifference + HomeScoreAdvantage + PlayerAge
##
##                      Df Sum of Sq    RSS   AIC
## - Temperature         1        16 183241 15883
## - PlayerHeight        1        17 183242 15883
## - Season              1        22 183248 15884
## - PlayDirection       1        24 183250 15884
## - Week                1        25 183251 15884
## - Humidity            1        31 183256 15884
## - GameClock           1        31 183256 15884
## - X                   1        32 183257 15884
```

```
## - HomeScoreAdvantage  1        65 183290 15884
## <none>                           183225 15885
## - Distance            1        89 183314 15885
## - Quarter             1       167 183392 15887
## - PlayerAge           1       211 183437 15888
## - TimeDifference      1       215 183440 15888
## - DefendersInTheBox   8      1699 184924 15908
##
## Step:  AIC=15883
## Yards ~ X + Season + Quarter + GameClock + Distance + DefendersInTheBox +
##     PlayDirection + PlayerHeight + Week + Humidity + TimeDifference +
##     HomeScoreAdvantage + PlayerAge
##
##                      Df Sum of Sq    RSS   AIC
## - PlayerHeight        1        17 183259 15882
## - Season              1        24 183266 15882
## - PlayDirection       1        24 183266 15882
## - GameClock           1        31 183272 15882
## - X                   1        31 183273 15882
## - Humidity            1        41 183283 15882
## - HomeScoreAdvantage  1        63 183304 15883
## <none>                           183241 15883
## - Distance            1        89 183331 15883
## - Week                1        89 183331 15883
## - Quarter             1       167 183408 15885
## - PlayerAge           1       203 183444 15886
## - TimeDifference      1       211 183453 15886
## - DefendersInTheBox   8      1698 184939 15906
##
## Step:  AIC=15882
## Yards ~ X + Season + Quarter + GameClock + Distance + DefendersInTheBox +
##     PlayDirection + Week + Humidity + TimeDifference + HomeScoreAdvantage +
##     PlayerAge
##
##                      Df Sum of Sq    RSS   AIC
## - PlayDirection       1        25 183283 15880
## - Season              1        26 183285 15880
## - GameClock           1        32 183291 15880
## - X                   1        32 183291 15881
## - Humidity            1        40 183299 15881
## - HomeScoreAdvantage  1        67 183326 15881
## <none>                           183259 15882
## - Distance            1        88 183347 15882
## - Week                1        90 183349 15882
## - Quarter             1       170 183429 15884
## - TimeDifference      1       211 183470 15885
## - PlayerAge           1       230 183489 15885
## - DefendersInTheBox   8      1688 184946 15904
##
## Step:  AIC=15880
## Yards ~ X + Season + Quarter + GameClock + Distance + DefendersInTheBox +
##     Week + Humidity + TimeDifference + HomeScoreAdvantage + PlayerAge
##
##                      Df Sum of Sq    RSS   AIC
```

```
## - X                   1        20 183303 15879
## - Season              1        25 183309 15879
## - GameClock           1        31 183314 15879
## - Humidity            1        40 183323 15879
## - HomeScoreAdvantage  1        67 183351 15880
## <none>                           183283 15880
## - Distance            1        88 183371 15880
## - Week                1        92 183375 15880
## - Quarter             1       172 183455 15882
## - TimeDifference      1       208 183491 15883
## - PlayerAge           1       230 183513 15884
## - DefendersInTheBox   8      1684 184967 15903
##
## Step:  AIC=15879
## Yards ~ Season + Quarter + GameClock + Distance + DefendersInTheBox +
##     Week + Humidity + TimeDifference + HomeScoreAdvantage + PlayerAge
##
##                       Df Sum of Sq    RSS   AIC
## - Season               1        26 183329 15877
## - GameClock            1        31 183335 15877
## - Humidity             1        41 183345 15878
## - HomeScoreAdvantage   1        67 183370 15878
## <none>                           183303 15879
## - Distance             1        90 183393 15879
## - Week                 1        90 183394 15879
## - Quarter              1       172 183476 15881
## - TimeDifference       1       207 183510 15882
## - PlayerAge            1       229 183532 15882
## - DefendersInTheBox    8      1683 184987 15901
##
## Step:  AIC=15877
## Yards ~ Quarter + GameClock + Distance + DefendersInTheBox +
##     Week + Humidity + TimeDifference + HomeScoreAdvantage + PlayerAge
##
##                       Df Sum of Sq    RSS   AIC
## - GameClock            1        32 183361 15876
## - Humidity             1        36 183366 15876
## - HomeScoreAdvantage   1        64 183393 15877
## <none>                           183329 15877
## - Distance             1        90 183419 15877
## - Week                 1        90 183419 15877
## - Quarter              1       172 183501 15879
## - TimeDifference       1       211 183540 15880
## - PlayerAge            1       239 183568 15881
## - DefendersInTheBox    8      1717 185046 15900
##
## Step:  AIC=15876
## Yards ~ Quarter + Distance + DefendersInTheBox + Week + Humidity +
##     TimeDifference + HomeScoreAdvantage + PlayerAge
##
##                       Df Sum of Sq    RSS   AIC
## - Humidity             1        37 183398 15875
## - HomeScoreAdvantage   1        64 183425 15876
## <none>                           183361 15876
```

```
## - Week                1        89 183450 15876
## - Distance            1        90 183451 15876
## - Quarter             1       175 183536 15878
## - TimeDifference      1       212 183573 15879
## - PlayerAge           1       241 183602 15880
## - DefendersInTheBox   8      1706 185068 15899
##
## Step:  AIC=15875
## Yards ~ Quarter + Distance + DefendersInTheBox + Week + TimeDifference +
##     HomeScoreAdvantage + PlayerAge
##
##                       Df Sum of Sq    RSS   AIC
## - HomeScoreAdvantage  1        61 183459 15874
## - Week                1        86 183484 15875
## <none>                            183398 15875
## - Distance            1        92 183490 15875
## - Quarter             1       175 183573 15877
## - TimeDifference      1       212 183610 15878
## - PlayerAge           1       235 183633 15878
## - DefendersInTheBox   8      1700 185098 15898
##
## Step:  AIC=15874
## Yards ~ Quarter + Distance + DefendersInTheBox + Week + TimeDifference +
##     PlayerAge
##
##                     Df Sum of Sq    RSS   AIC
## <none>                           183459 15874
## - Week               1        88 183547 15874
## - Distance           1        91 183550 15874
## - Quarter            1       166 183625 15876
## - TimeDifference     1       210 183669 15877
## - PlayerAge          1       232 183692 15878
## - DefendersInTheBox  8      1695 185154 15897
```

```
cat("Stepwise Backward Model on test set")
```

```
## Stepwise Backward Model on test set
```

```
summary(test_backward_step)
```

```
##
## Call:
## lm(formula = Yards ~ Quarter + Distance + DefendersInTheBox +
##     Week + TimeDifference + PlayerAge, data = NFL_DATA_HOLDOUT_Final)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -16.34  -3.30  -1.26   1.34  87.21
##
## Coefficients:
##                     Estimate Std. Error t value  Pr(>|t|)
## (Intercept)           4.9791     1.0588    4.70 0.0000027 ***
## Quarter               0.1742     0.0897    1.94     0.052 .
## Distance              0.0390     0.0271    1.44     0.150
## DefendersInTheBox.L  -7.7622     1.8948   -4.10 0.0000427 ***
```

```
## DefendersInTheBox.Q   0.7879     1.7613    0.45     0.655
## DefendersInTheBox.C  -1.5955     1.5613   -1.02     0.307
## DefendersInTheBox^4   1.8728     1.3789    1.36     0.174
## DefendersInTheBox^5   0.1048     1.1624    0.09     0.928
## DefendersInTheBox^6   0.2640     0.9069    0.29     0.771
## DefendersInTheBox^7  -0.3332     0.6072   -0.55     0.583
## DefendersInTheBox^8  -0.3392     0.3134   -1.08     0.279
## Week                 -0.0292     0.0206   -1.41     0.158
## TimeDifference        0.4770     0.2182    2.19     0.029 *
## PlayerAge            -0.0746     0.0324   -2.30     0.021 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 6.62 on 4180 degrees of freedom
## Multiple R-squared:  0.015,  Adjusted R-squared:  0.012
## F-statistic: 4.91 on 13 and 4180 DF,  p-value: 0.0000000128
```

```
# Bootstrap sample distribution holders

Season2018_Hold = rep(0, 1000) # 2
Distance_Hold = rep(0, 1000) # 3
Defender_L = rep(0, 1000)
Defender_Q = rep(0, 1000)
Defender_C = rep(0, 1000)
Df_4 = rep(0, 1000)
Df_5 = rep(0, 1000)
Df_6 = rep(0, 1000)
Df_7 = rep(0, 1000)
Df_8 = rep(0, 1000)
FB = rep(0, 1000)
HB = rep(0, 1000)
QB = rep(0, 1000)
RB = rep(0, 1000)
TE = rep(0, 1000)
WR = rep(0, 1000)
Temp_Hold = rep(0, 1000)
Humidty_Hold = rep(0, 1000)
Time_Diff_Hold = rep(0, 1000)
Home_Adva_Hold = rep(0, 1000)
Age_Hold = rep(0, 1000)
```

Bootstrap

```
# backward_step  # This is the BackwardStep Model
# NFL_DATA_TRAIN_Filtered_Final # this is where the data is kept
# NFL_Train_Total_Model = lm(Yards ~ ., data=NFL_DATA_TRAIN_Filtered_Final)
# summary(model_boot)$coefficients[2]

set.seed(121)
for(i in 1:1000){
  Sample_Train_Data = sample_n(NFL_DATA_TRAIN_Filtered_Final, 16761, replace=TRUE)
  model_boot = lm(Yards ~ Season + Distance + DefendersInTheBox +
```

```
                  Position + Temperature + Humidity + TimeDifference +
                  HomeScoreAdvantage + PlayerAge, data=Sample_Train_Data)
  # Grab the coefficient
  Season2018_Hold[i] = summary(model_boot)$coefficients[2]
  Distance_Hold[i] = summary(model_boot)$coefficients[3]#3
  Defender_L[i] = summary(model_boot)$coefficients[4]
  Defender_Q[i] = summary(model_boot)$coefficients[5]
  Defender_C[i] = summary(model_boot)$coefficients[6]
  Df_4[i] = summary(model_boot)$coefficients[7]
  Df_5[i] = summary(model_boot)$coefficients[8]
  Df_6[i] = summary(model_boot)$coefficients[9]
  Df_7[i] = summary(model_boot)$coefficients[10]
  Df_8[i] = summary(model_boot)$coefficients[11]
  FB[i] = summary(model_boot)$coefficients[12]
  HB[i] = summary(model_boot)$coefficients[13]
  QB[i] = summary(model_boot)$coefficients[14]
  RB[i] = summary(model_boot)$coefficients[15]
  TE[i] = summary(model_boot)$coefficients[16]
  WR[i] = summary(model_boot)$coefficients[17]
  Temp_Hold[i] = summary(model_boot)$coefficients[18]
  Humidty_Hold[i] = summary(model_boot)$coefficients[19]
  Time_Diff_Hold[i] = summary(model_boot)$coefficients[20]
  Home_Adva_Hold[i] = summary(model_boot)$coefficients[21]
  Age_Hold[i] = summary(model_boot)$coefficients[22]
}
```

```
calculate_CI <- function(dist){
  se_bootrap = sd(dist) / sqrt(length(dist))
  min_conf = mean(dist) - (1.96 * se_bootrap)
  max_conf = mean(dist) + (1.96 * se_bootrap)
  # Quantile Bootstrap
  sorted_dist = sort(dist)
  min = sorted_dist[.025 * length(sorted_dist)]
  max = sorted_dist[.975 * length(sorted_dist)]
  return(c(min_conf,max_conf, min,max))
}
```

```
calculate_CI(Season2018_Hold)
```

```
## [1] 0.29684 0.30920 0.10857 0.49517
```

```
calculate_CI(Distance_Hold)
```

```
## [1] 0.078872 0.080400 0.054514 0.104388
```

```
calculate_CI(Defender_L)
```

```
## [1] -7.7990 -7.6771 -9.6550 -5.8412
```

```
calculate_CI(Defender_Q)
```

```
## [1]  1.65068  1.77067 -0.23781  3.66113
```

```
calculate_CI(Defender_C)
```

```
## [1] -1.4051 -1.2995 -3.0751  0.2877
```

```
calculate_CI(Df_4)
```

```
## [1]  0.72537  0.81084 -0.61647  2.09134
```

```
calculate_CI(Df_5)
```

```
## [1]  0.21223  0.27931 -0.79968  1.37916
```

```
calculate_CI(Df_6)
```

```
## [1]  0.53384  0.58808 -0.33052  1.37683
```

```
calculate_CI(Df_7)
```

```
## [1] -0.0061014  0.0317655 -0.5721019  0.6239428
```

```
calculate_CI(Df_8)
```

```
## [1] 0.2925951 0.3125357 0.0015328 0.6175797
```

```
calculate_CI(FB)
```

```
## [1]  0.022648  0.084107 -0.925562  1.071911
```

```
calculate_CI(HB)
```

```
## [1] -1.23120 -1.11945 -2.87400  0.73868
```

```
calculate_CI(QB)
```

```
## [1]  0.12078  0.16695 -0.62256  0.83467
```

```
calculate_CI(RB)
```

```
## [1]  1.3832  1.5736 -1.5631  4.3932
```

```
calculate_CI(TE)
```

```
## [1] 1.68869 1.75826 0.63754 2.79246
```

```
calculate_CI(WR)
```

```
## [1] -0.0076818 -0.0073097 -0.0129717 -0.0014519
```

```
calculate_CI(Temp_Hold)
```

```
## [1] -0.0031879 -0.0028899 -0.0077618  0.0016044
```

```
calculate_CI(Humidty_Hold)
```

```
## [1]  0.082352  0.096248 -0.127267  0.300684
```

```
calculate_CI(Time_Diff_Hold)
```

```
## [1] -0.0076761 -0.0071092 -0.0166968  0.0015104
```

```
calculate_CI(Home_Adva_Hold)
```

```
## [1] -0.047159 -0.045177 -0.077090 -0.014881
```

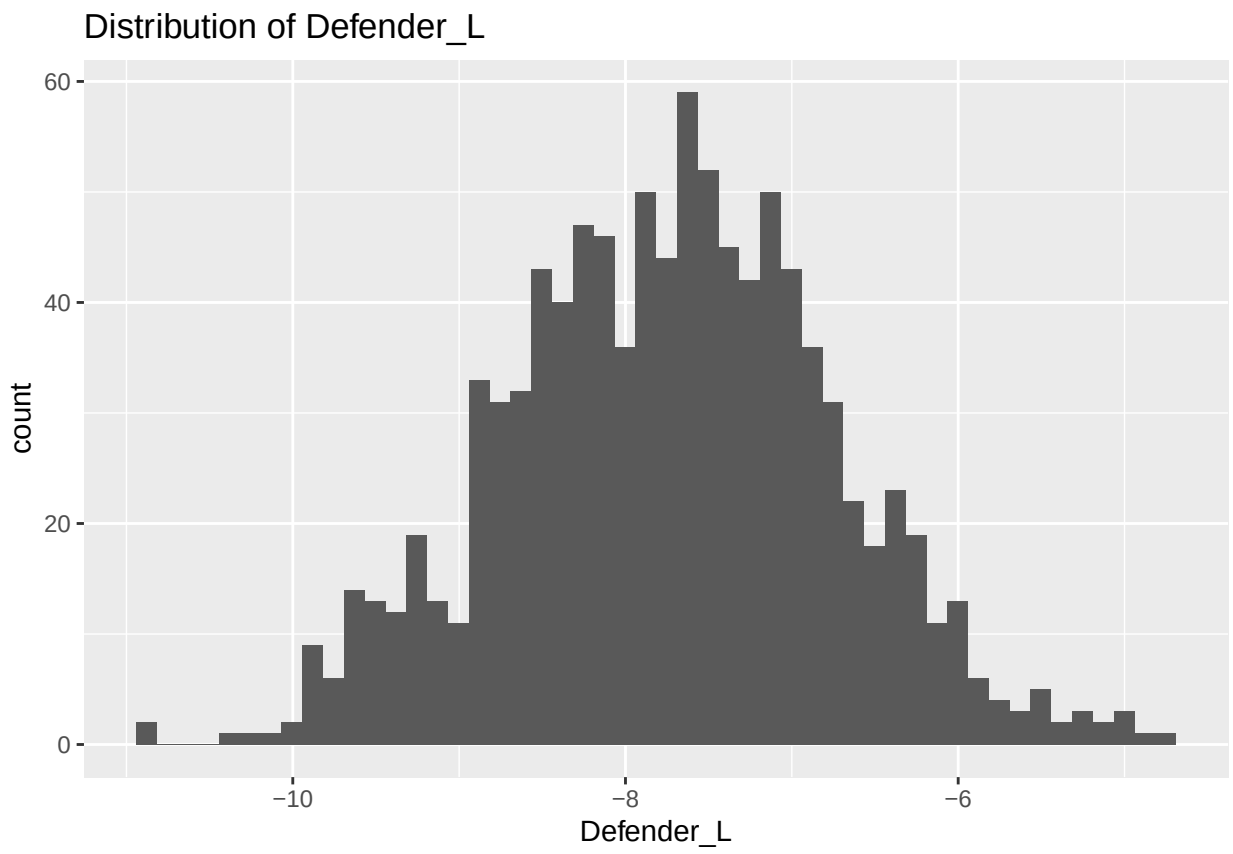
```
calculate_CI(Age_Hold)
```

```
## [1] 0.82705 0.83071 0.77654 0.89219
```

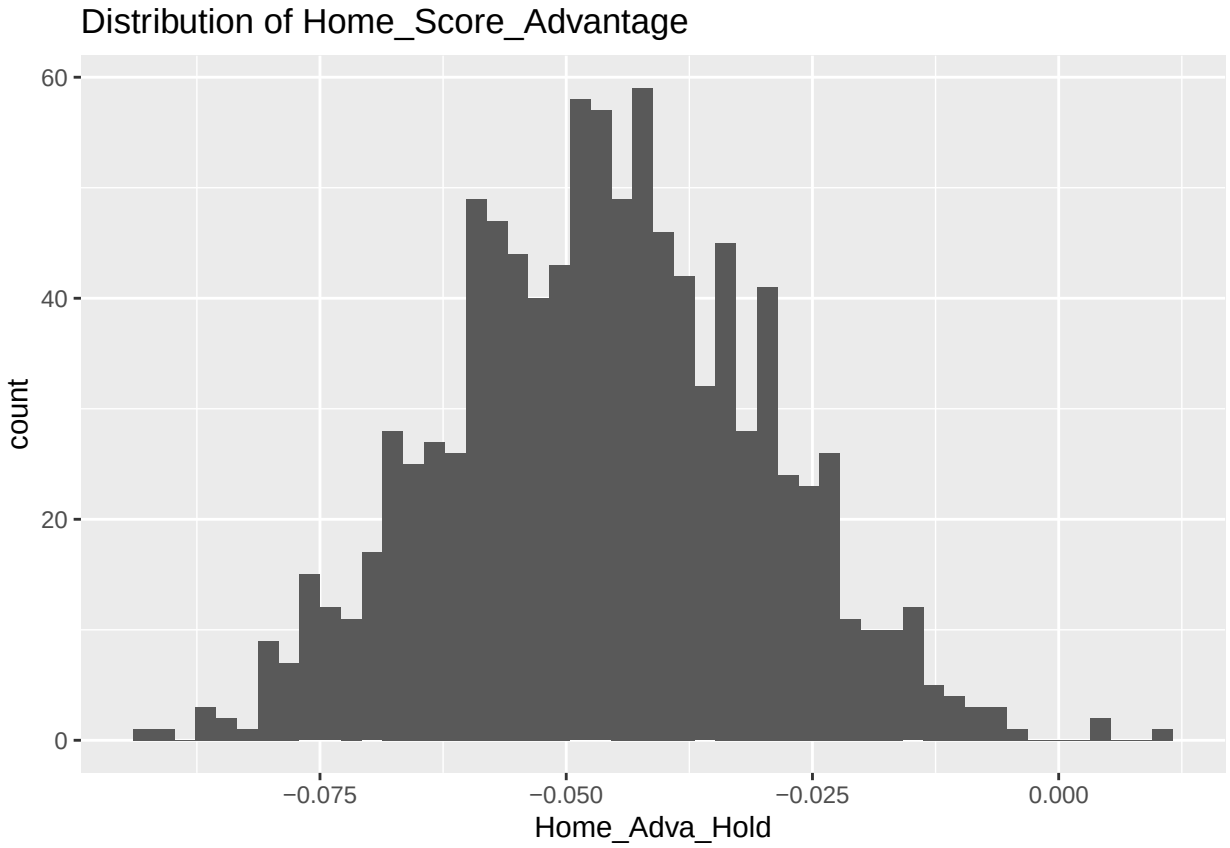
```
confint(backward_step)
```

```
##                             2.5 %      97.5 %
## (Intercept)           3.79127562 12.42872468
## Season2018            0.11070534  0.50195106
## GameClock             0.00015695  0.00089477
## Distance              0.05179192  0.10565643
## DefendersInTheBox.L -9.82963123 -5.63471996
## DefendersInTheBox.Q -0.28595010  3.77681310
## DefendersInTheBox.C -3.17000012  0.34611021
## DefendersInTheBox^4 -0.73766275  2.15052841
## DefendersInTheBox^5 -0.85220605  1.41165027
## DefendersInTheBox^6 -0.28102709  1.39356774
## DefendersInTheBox^7 -0.50656802  0.59351201
## DefendersInTheBox^8  0.02649158  0.59745126
## PlayerHeight        -0.09608546  0.01308703
## PositionHB          -1.19316377  1.39767875
## PositionQB          -3.01688181  1.06884733
## PositionRB          -0.99955461  1.29505478
## PositionTE          -1.21021647  4.59852705
## PositionWR           0.45763126  3.03607147
## Temperature         -0.01274723 -0.00165640
## HomeScoreAdvantage  -0.01645468  0.00158494
## PlayerAge           -0.08230533 -0.01801529
```

```
ggplot() +
  geom_histogram(mapping = aes(x = Defender_L), bins = 50) +
  ggtitle("Distribution of Defender_L")
```



```r
ggplot() +
  geom_histogram(mapping = aes(x = Home_Adva_Hold), bins = 50) +
  ggtitle("Distribution of Home_Score_Advantage")
```



Classification. Outcome Variable: NFL Yards >= distance. (Whether or not they get a first down)

With all Covariates for training set

```r
NFL_Train_Total_Model_c <- NFL_DATA_TRAIN_Filtered_Final
NFL_Train_Total_Model_c$FirstDown <- ifelse(
  NFL_Train_Total_Model_c$Yards >= NFL_Train_Total_Model_c$Distance, 1, 0)
NFL_Train_Total_Model_c$FirstDown <-
  factor(NFL_Train_Total_Model_c$FirstDown)
NFL_Train_Total_Model_c <- select(NFL_Train_Total_Model_c, -Yards) #remove colinear response variable f
```

For test set

```r
NFL_HOLDOUT_C <- NFL_DATA_HOLDOUT_Final
NFL_HOLDOUT_C$FirstDown <- ifelse(
  NFL_HOLDOUT_C$Yards >= NFL_HOLDOUT_C$Distance, 1, 0)
```

```
NFL_HOLDOUT_C$FirstDown <-
  factor(NFL_HOLDOUT_C$FirstDown)
NFL_HOLDOUT_C <- select(NFL_HOLDOUT_C, -Yards) #remove colinear response variable from regression
```

Implementing Cross-Fold Validation for Classification to calculate validation error

and test error

```
set.seed(122)
k = 10

f <- createFolds(y=NFL_Train_Total_Model_c$FirstDown, k)
train_fold <- function (i) {
  NFL_Train_Total_Model_c[-unlist(f[i]),]
}

test_fold <- function (i) {
  NFL_Train_Total_Model_c[unlist(f[i]),]
}

accuracyR <- c()

for (i in 1:k) {
  glm_Model = glm(FirstDown ~ ., data=train_fold(i),
                              family = binomial)
  predict_result <- predict(glm_Model, newdata=test_fold(i), type="response")
  predict_logit <- ifelse(predict_result > 0.5, 1, 0)
  t <- table(predict_logit, test_fold(i)$FirstDown)
  accuracyR[i] = (t[1,1]+t[2,2])/dim(test_fold(i))[1]
}
cat("Error of 10-fold validation is: ", 1 - mean(accuracyR), "\n")
```

```
## Error of 10-fold validation is:  0.18093
```