BIOS512_FinalProject_Williams

November 25, 2025

BIOS512 FINAL PROJECT BELLA WILLIAMS

```
[2]: library(readr)
     library(tidyverse)
```

```
  Attaching core tidyverse packages                tidyverse
2.0.0
 dplyr     1.1.2      purrr     1.0.1
 forcats   1.0.0      stringr   1.5.0
 ggplot2   3.4.2      tibble    3.2.1
 lubridate 1.9.2      tidyr     1.3.0
  Conflicts
tidyverse_conflicts()
 dplyr::filter() masks stats::filter()
 dplyr::lag()    masks stats::lag()
 Use the conflicted package
(<http://conflicted.r-lib.org/>) to force all conflicts to
become errors
```

```
[3]: install.packages('fivethirtyeight')
     install.packages('fivethirtyeightdata', repos = 'https://fivethirtyeightdata.
      ↪github.io/drat/', type = 'source')
```

```
Installing package into '/srv/rlibs'
(as 'lib' is unspecified)

Installing package into '/srv/rlibs'
(as 'lib' is unspecified)
```

```
[4]: library(fivethirtyeight)
     data("airline_safety")
```

```
[5]: install.packages('readr')
     library(readr)
```

```
Installing package into '/srv/rlibs'
(as 'lib' is unspecified)
```

[6]:

```
head(airline_safety)
```

A tibble: 6 × 9

airline <chr>	incl_reg_subsidiaries <lgl>	avail_seat_km_per_week <dbl>	incidents_85_99 <int>
Aer Lingus	FALSE	320906734	2
Aeroflot	TRUE	1197672318	76
Aerolineas Argentinas	FALSE	385803648	6
Aeromexico	TRUE	596871813	3
Air Canada	FALSE	1865253802	2
Air France	FALSE	3004002661	14

[7]:

```
str(airline_safety)

summary(airline_safety)

mean(airline_safety$fatalities_85_99)
mean(airline_safety$fatalities_00_14)
```

```
tibble [56 × 9] (S3: tbl_df/tbl/data.frame)
 $ airline               : chr [1:56] "Aer Lingus" "Aeroflot" "Aerolineas
Argentinas" "Aeromexico" …
 $ incl_reg_subsidiaries : logi [1:56] FALSE TRUE FALSE TRUE FALSE FALSE …
 $ avail_seat_km_per_week: num [1:56] 3.21e+08 1.20e+09 3.86e+08 5.97e+08
1.87e+09 …
 $ incidents_85_99       : int [1:56] 2 76 6 3 2 14 2 3 5 7 …
 $ fatal_accidents_85_99 : int [1:56] 0 14 0 1 0 4 1 0 0 2 …
 $ fatalities_85_99      : int [1:56] 0 128 0 64 0 79 329 0 0 50 …
 $ incidents_00_14       : int [1:56] 0 6 1 5 2 6 4 5 5 4 …
 $ fatal_accidents_00_14 : int [1:56] 0 1 0 0 0 2 1 1 1 0 …
 $ fatalities_00_14      : int [1:56] 0 88 0 0 0 337 158 7 88 0 …
```

```
   airline          incl_reg_subsidiaries avail_seat_km_per_week
 Length:56          Mode :logical         Min.   :2.594e+08     
 Class  :character  FALSE:40              1st Qu.:4.740e+08     
 Mode   :character  TRUE :16              Median :8.029e+08     
                                          Mean   :1.385e+09     
                                          3rd Qu.:1.847e+09     
                                          Max.   :7.139e+09     
 incidents_85_99  fatal_accidents_85_99 fatalities_85_99 incidents_00_14
 Min.   : 0.000   Min.   : 0.000        Min.   :  0.0    Min.   : 0.000 
 1st Qu.: 2.000   1st Qu.: 0.000        1st Qu.:  0.0    1st Qu.: 1.000 
 Median : 4.000   Median : 1.000        Median : 48.5    Median : 3.000 
 Mean   : 7.179   Mean   : 2.179        Mean   :112.4    Mean   : 4.125 
 3rd Qu.: 8.000   3rd Qu.: 3.000        3rd Qu.:184.2    3rd Qu.: 5.250 
 Max.   :76.000   Max.   :14.000        Max.   :535.0    Max.   :24.000 
 fatal_accidents_00_14 fatalities_00_14
 Min.   :0.0000        Min.   :  0.00  
 1st Qu.:0.0000        1st Qu.:  0.00  
 Median :0.0000        Median :  0.00  
 Mean   :0.6607        Mean   : 55.52  
 3rd Qu.:1.0000        3rd Qu.: 83.25  
 Max.   :3.0000        Max.   :537.00  
```

112.410714285714

55.5178571428571

Checking Missingness

```
[8]: sum(is.na(airline_safety))
     colSums(is.na(airline_safety))
```

0

airline 0 **incl_reg_subsidiaries** 0 **avail_seat_km_per_week** 0 **incidents_85_99** 0 **fatal_accidents_85_99** 0 **fatalities_85_99** 0 **incidents_00_14** 0 **fatal_accidents_00_14** 0 **fatalities_00_14** 0

Checking Duplicates

```
[11]: nrow(airline_safety)
      nrow(distinct(airline_safety))

      airline_safety %>%
        group_by(airline) %>%
        tally() %>%
        filter(n > 1)
```

56

56

A tibble: 0 × 2

airline	n
<chr>	<int>

Data Description (Codebook)

The airline_safety dataset contains safety records for 56 airlines from 1985–2014. The data were originally compiled by FiveThirtyEight and include operational exposure (airline size) and incident/fatality counts for two time periods. No missing values are present in this dataset.

Variable	Type	Description
airline	character	Airline name
incl_reg_subsidiaries	logical	TRUE if safety numbers include regional subsidiaries, otherwise FALSE

Variable	Type	Description
avail_seat_km_per_week	numeric	Airline size, measured as available seat–kilometers flown per week
incidents_85_99	integer	Total incidents from 1985–1999
fatal_accidents_85_99	integer	Fatal accidents from 1985–1999
fatalities_85_99	integer	Total fatalities from 1985–1999
incidents_00_14	integer	Total incidents from 2000–2014
fatal_accidents_00_14	integer	Fatal accidents from 2000–2014
fatalities_00_14	integer	Total fatalities from 2000–2014

[13]:

```r
airline_safety %>%
  group_by(incl_reg_subsidiaries) %>%
  tally() %>%
  arrange(desc(n))
```

A tibble: 2 × 2

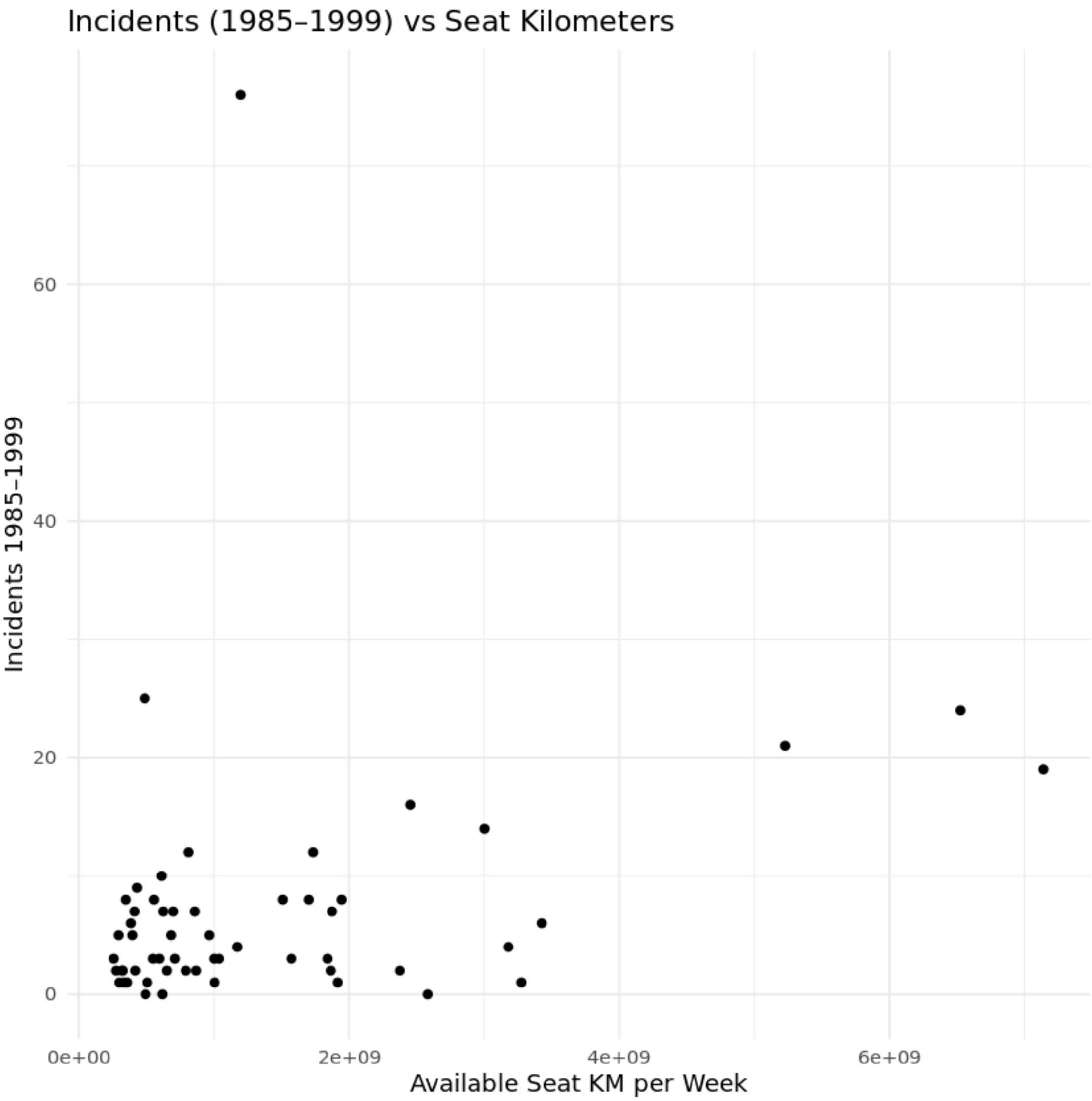
incl_reg_subsidiaries <lgl>	n <int>
FALSE	40
TRUE	16

Exploratory Figures (1-4)

1.

[14]:

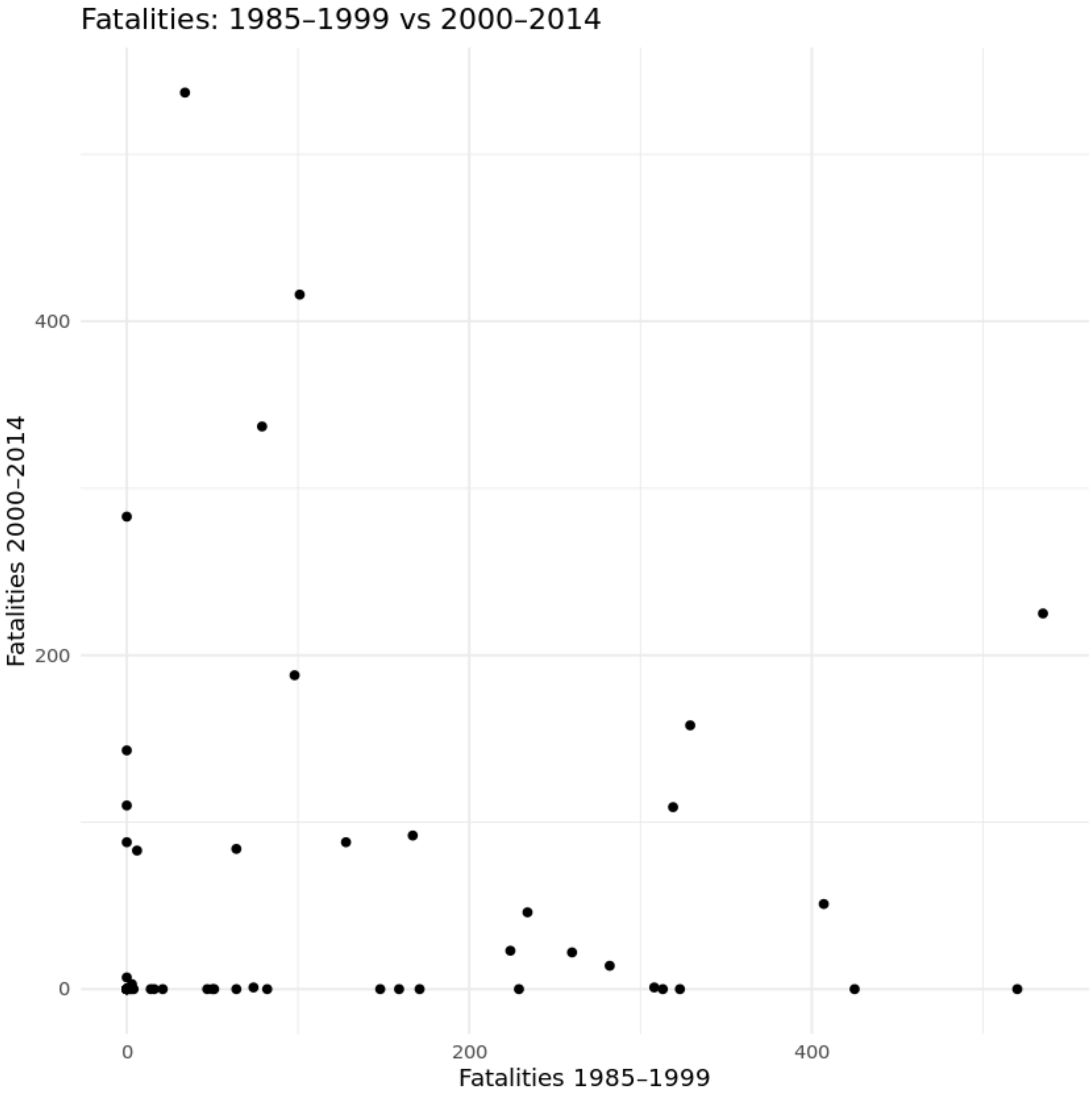
```r
p1 <- ggplot(
     airline_safety,
     aes(x = avail_seat_km_per_week, y = incidents_85_99)
 ) +
     geom_point() +
     labs(
         title = "Incidents (1985-1999) vs Seat Kilometers",
         x = "Available Seat KM per Week",
         y = "Incidents 1985-1999"
     ) +
     theme_minimal()

 ggsave("plot1_incidents_vs_seats.png", p1, width = 6, height = 4)

 print(p1)
```



2.

```
[18]: p2 <- ggplot(
          airline_safety,
          aes(x = fatalities_85_99, y = fatalities_00_14)
      ) +
          geom_point() +
          labs(
              title = "Fatalities: 1985-1999 vs 2000-2014",
              x = "Fatalities 1985-1999",
              y = "Fatalities 2000-2014"
          ) +
          theme_minimal()
```

```
ggsave("plot2_fatalities_comparison.png", p2, width = 6, height = 4)

print(p2)
```

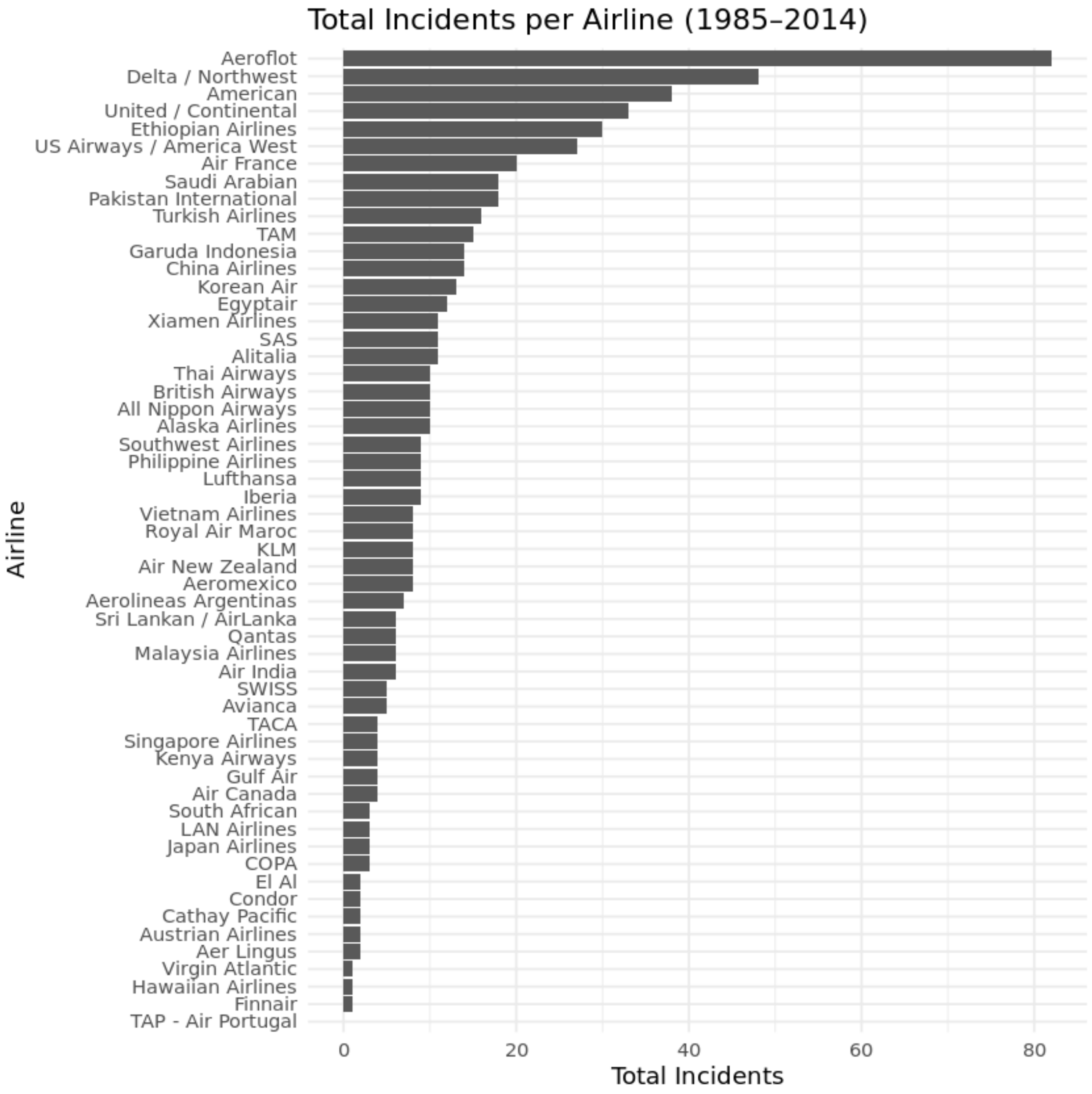


3.

[19]:

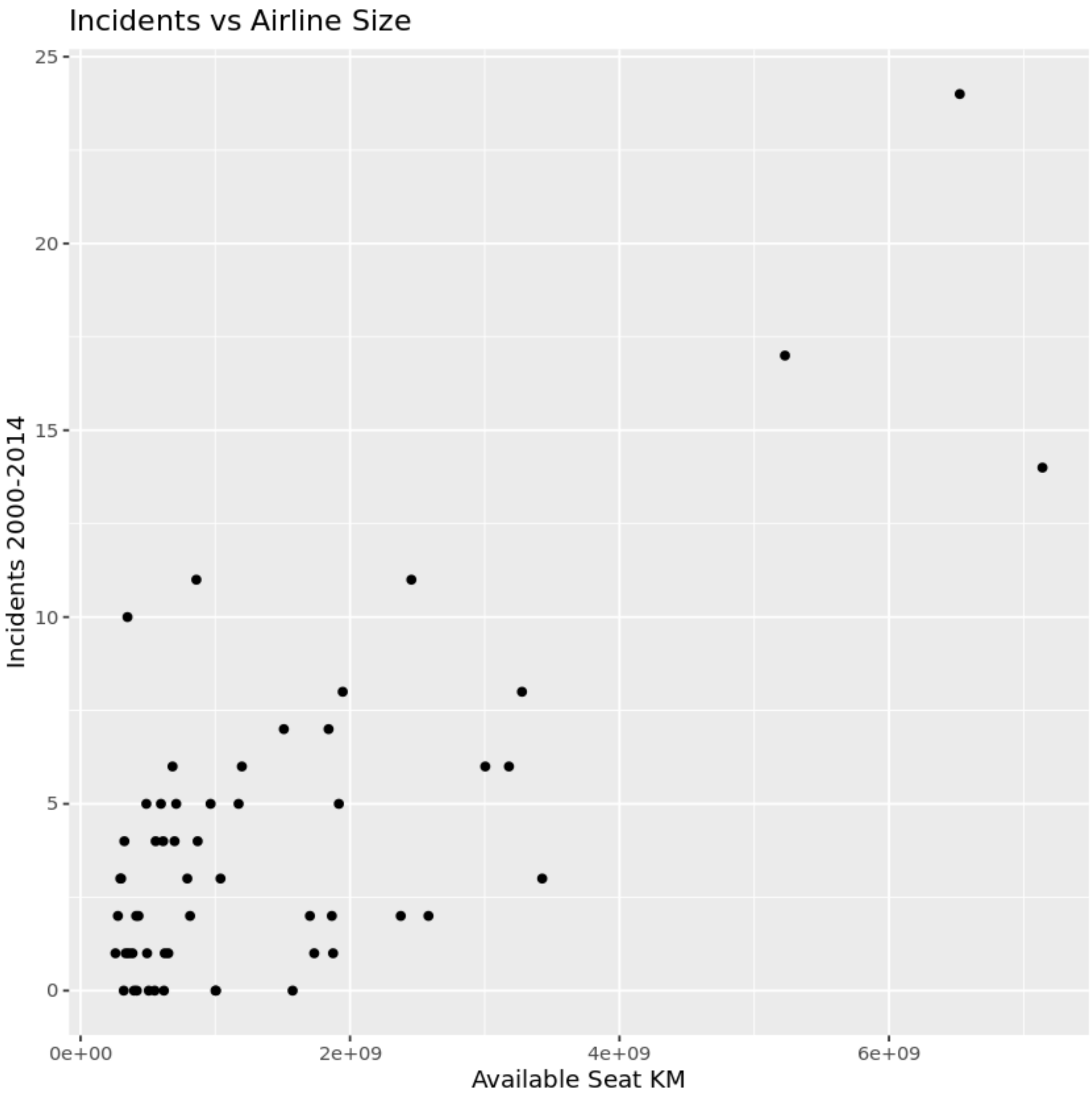
```
airline_safety$total_incidents <- airline_safety$incidents_85_99 +
                                  airline_safety$incidents_00_14

p3 <- ggplot(
    airline_safety,
    aes(x = reorder(airline, total_incidents), y = total_incidents)
```

```r
) +
    geom_col() +
    coord_flip() +
    labs(
        title = "Total Incidents per Airline (1985-2014)",
        x = "Airline",
        y = "Total Incidents"
    ) +
    theme_minimal()

ggsave("plot3_total_incidents_bar.png", p3, width = 6, height = 6)

print(p3)
```



4.

```
[20]: ggplot(airline_safety, aes(x = avail_seat_km_per_week, y = incidents_00_14)) +
          geom_point() +
          labs(title = "Incidents vs Airline Size", x="Available Seat KM",␣
       ↪y="Incidents 2000-2014")
```



Analysis Method 1: Dimensionality Reduction

```
[22]: sapply(airline_safety, class)

      airline_safety$class <- cut(
          airline_safety$fatalities_00_14,
          breaks = c(-Inf, 0, 50, Inf),
```

```r
    labels = c("none", "low", "high")
)

airline_safety$class <- as.factor(airline_safety$class)

sapply(
    airline_safety[ , sapply(airline_safety, is.numeric)],
    function(x) {
        c(
            Mean = mean(x),
            SD   = sd(x),
            Var  = var(x),
            Min  = min(x),
            Max  = max(x)
        )
    }
)

airline_scaled <- airline_safety %>%
    mutate(across(
        .cols = where(is.numeric),
        .fns  = ~ as.numeric(scale(.))
    ))

airline_numeric <- airline_scaled %>%
  select(where(is.numeric))

airline_pca <- prcomp(
    airline_numeric,
    center = FALSE,
    scale. = FALSE
)

summary(airline_pca)

airline_pca$rotation

pc_scores <- as_tibble(airline_pca$x) %>%
  mutate(class = airline_safety$class)

ggplot(pc_scores, aes(x = PC1, y = PC2, color = class)) +
  geom_point(size = 3) +
  labs(
    title = "PCA of Airline Safety Data",
    x = "Principal Component 1",
    y = "Principal Component 2",
    color = "Class"
  ) +
  theme_minimal() +
  coord_fixed()
```

airline 'character' **incl__reg__subsidiaries** 'logical' **avail__seat__km__per__week** 'numeric' **incidents__85__99** 'integer' **fatal__accidents__85__99** 'integer' **fatalities__85__99** 'integer' **incidents__00__14** 'integer' **fatal__accidents__00__14** 'integer' **fatalities__00__14** 'integer' **total__incidents** 'integer' **class** 'factor'

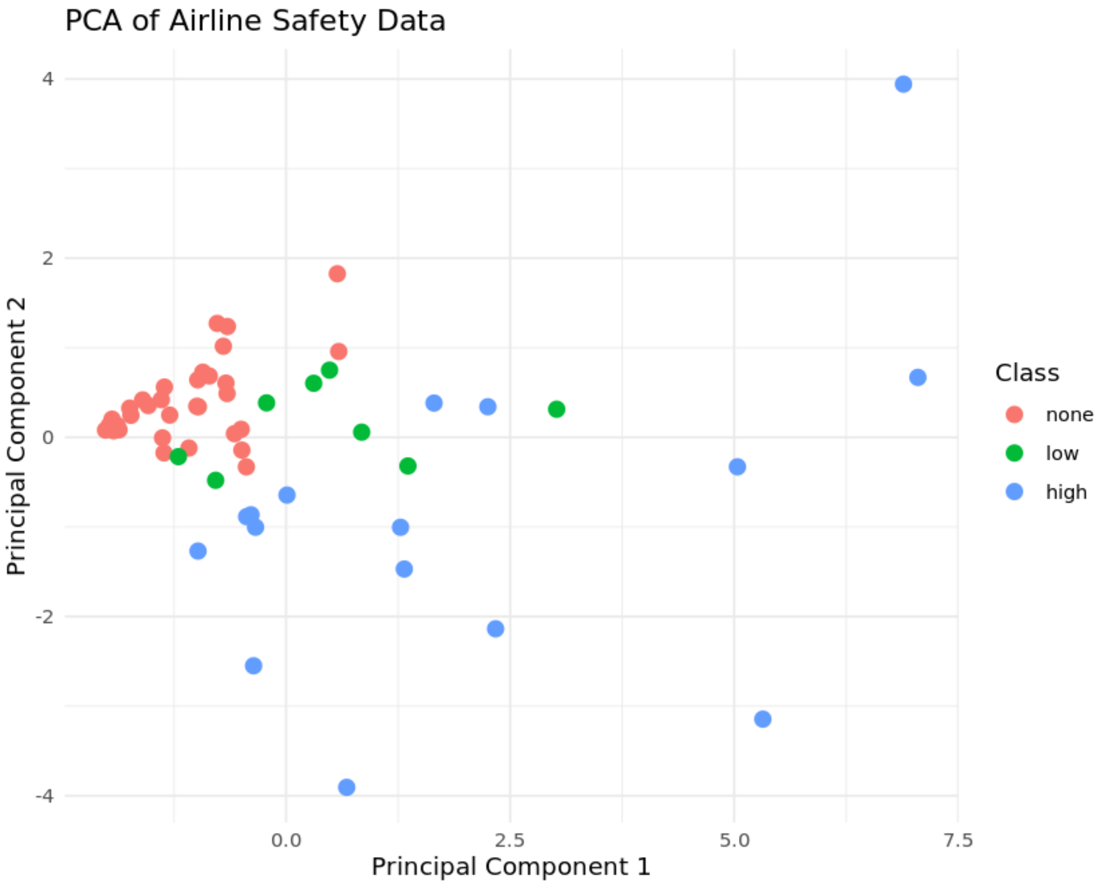
A matrix: 5 × 8 of type dbl

	avail_seat_km_per_week	incidents_85_99	fatal_accidents_85_99	fat
Mean	1.384621e+09	7.178571	2.178571	112
SD	1.465317e+09	11.035656	2.861069	140
Var	2.147154e+18	121.785714	8.185714	215
Min	2.593733e+08	0.000000	0.000000	0.0
Max	7.139291e+09	76.000000	14.000000	535

```
Importance of components:
                          PC1    PC2    PC3    PC4     PC5     PC6     PC7
Standard deviation     2.0713 1.1589 0.9765 0.9128 0.57437 0.42016 0.27089
Proportion of Variance 0.5363 0.1679 0.1192 0.1042 0.04124 0.02207 0.00917
Cumulative Proportion  0.5363 0.7042 0.8234 0.9275 0.96876 0.99083 1.00000
                             PC8
Standard deviation     1.393e-16
Proportion of Variance 0.000e+00
Cumulative Proportion  1.000e+00
```

A matrix: 8 × 8 of type dbl

	PC1	PC2	PC3	PC4	PC
avail_seat_km_per_week	0.3121938	-0.1584642	0.65910953	0.15023745	-0.
incidents_85_99	0.3882880	0.3249617	-0.37453597	0.26685886	-0.
fatal_accidents_85_99	0.4349471	0.2927389	-0.09931813	-0.04934381	-0.
fatalities_85_99	0.2255842	0.2884610	0.11597506	-0.88234766	-0.
incidents_00_14	0.3825740	-0.1659525	0.45019488	0.11162492	0.4
fatal_accidents_00_14	0.3483016	-0.4637203	-0.19373023	-0.15251234	0.4
fatalities_00_14	0.2135344	-0.6433906	-0.37142374	-0.15604098	-0.
total_incidents	0.4454508	0.2094157	-0.15433962	0.25529185	0.0



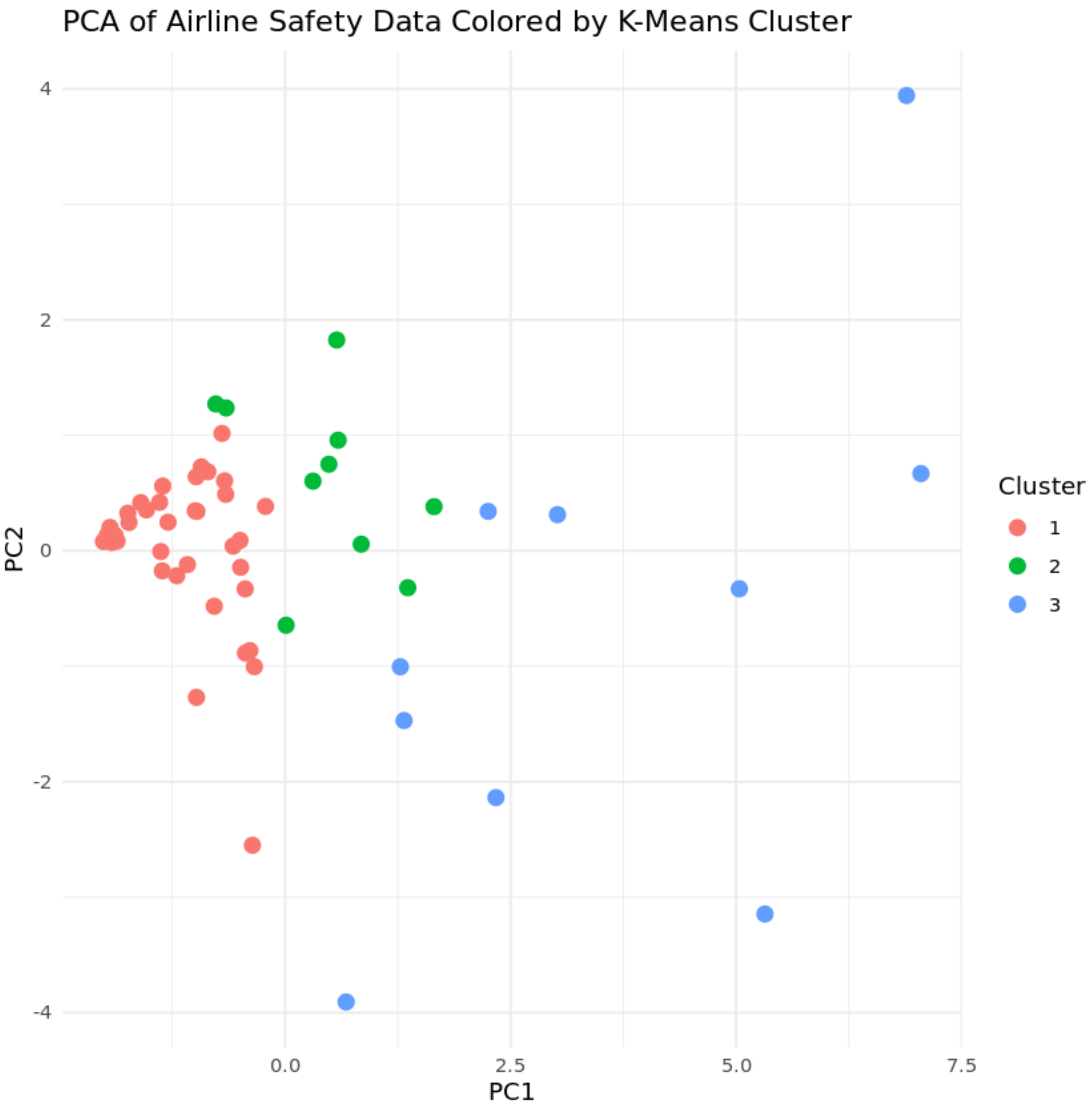
Analysis Method 2: Clustering

[23]:

```
airline_numeric <- airline_scaled %>%
  select(where(is.numeric))

label_randomly <- function(n_points, n_clusters){
  sample(1:n_clusters, size = n_points, replace = TRUE)
}

get_cluster_means <- function(data, labels){
  data %>%
    mutate(label__ = labels) %>%
    group_by(label__) %>%
    summarize(across(
      .cols = where(is.numeric),
      .fns  = mean,
      .names = "{.col}"
    )) %>%
    rename(label = label__) %>%
    ungroup() %>%
    arrange(label)
}

assign_cluster <- function(data, means){

  X <- as.matrix(data)
  C <- as.matrix(means %>% select(-label))

  X_sq <- rowSums(X * X)
  C_sq <- rowSums(C * C)

  dist_sq_matrix <- outer(X_sq, C_sq, FUN = "+") - 2 * (X %*% t(C))

  new_labels <- max.col(-dist_sq_matrix)

  return(new_labels)
}

kmeans_done <- function(old_means, new_means, eps = 1e-6){
  om <- old_means %>% select(-label) %>% as.matrix()
  nm <- new_means %>% select(-label) %>% as.matrix()

  distances <- sqrt(rowSums((om - nm)^2))

  mean(distances) < eps
}

mykmeans <- function(data, n_clusters, eps = 1e-6, max_iter = 100){

  labels <- label_randomly(nrow(data), n_clusters)

  old_means <- get_cluster_means(data, labels)

  done <- FALSE
  iter <- 0

  while (!done && iter < max_iter){

    labels <- assign_cluster(data, old_means)
    new_means <- get_cluster_means(data, labels)

    if (kmeans_done(old_means, new_means, eps)){
      done <- TRUE
    }

    old_means <- new_means
    iter <- iter + 1
  }

  if (iter == max_iter && !done) {
    warning("K-Means did not converge within the maximum number of iterations.")
  }

  cat(paste("K-Means converged after", iter, "iterations.\n"))

  return(list(labels = labels, means = new_means))
}

n_clusters <- 3

print(paste("Running custom mykmeans with k =", n_clusters))

my_results <- mykmeans(airline_numeric, n_clusters)

print("--- Custom mykmeans Results (Cluster Labels) ---")
print(my_results$labels)

print("--- Custom mykmeans Results (Cluster Means/Centroids) ---")
print(my_results$means)

airline_matrix <- as.matrix(airline_numeric)

print("\n--- RESULTS FROM R's BUILT-IN kmeans ---")

r_results <- stats::kmeans(airline_matrix, centers = n_clusters, nstart = 25)

print("Cluster Labels (R's kmeans):")
print(r_results$cluster)

print("Cluster Means (R's kmeans):")
print(r_results$centers)

pc_cluster_plot <- pc_scores %>%
  mutate(cluster = as.factor(my_results$labels))

ggplot(pc_cluster_plot, aes(PC1, PC2, color = cluster)) +
```

```r
  geom_point(size = 3) +
  labs(
    title = "PCA of Airline Safety Data Colored by K-Means Cluster",
    color = "Cluster"
  ) +
  theme_minimal()
```

```
[1] "Running custom mykmeans with k = 3"
K-Means converged after 6 iterations.
[1] "--- Custom mykmeans Results (Cluster Labels) ---"
 [1] 1 3 1 1 1 3 2 1 1 1 1 3 1 2 1 1 2 1 1 3 2 1 3 1 2 1 1 1 2 1 1 2 1 1 3 2 1 1
[39] 1 1 2 1 1 1 1 1 1 3 1 2 3 3 3 1 1 1
[1] "--- Custom mykmeans Results (Cluster Means/Centroids) ---"
# A tibble: 3 × 9
  label avail_seat_km_per_week incidents_85_99 fatal_accidents_85_99
  <int>                  <dbl>
<dbl>                 <dbl>
1     1                 -0.233
-0.366
-0.480
2     2                 -0.299
0.0291                 0.322
3     3                  1.14           1.29                   1.41
#   5 more variables: fatalities_85_99 <dbl>, incidents_00_14 <dbl>,
#   fatal_accidents_00_14 <dbl>, fatalities_00_14 <dbl>, total_incidents

<dbl>
[1] "\n--- RESULTS FROM R's BUILT-IN kmeans ---"
[1] "Cluster Labels (R's kmeans):"
 [1] 1 3 1 1 1 2 2 1 1 1 1 3 1 1 1 1 2 1 1 3 2 1 2 1 2 1 1 1 1 2 1 2 1 1 2 2 1 1
[39] 1 1 2 1 1 1 1 1 1 2 1 2 2 3 2 1 1 1
[1] "Cluster Means (R's kmeans):"
  avail_seat_km_per_week incidents_85_99 fatal_accidents_85_99 fatalities_85_99
1             -0.2213781      -0.3590502            -0.4497199       -0.4000309
2             -0.1160204       0.2133776             0.4036121        0.7570735
3              2.4828238       2.5210488             2.6463637        0.8612607
  incidents_00_14 fatal_accidents_00_14 fatalities_00_14 total_incidents
1      -0.3724040            -0.5491255       -0.3930658      -0.4181727
2       0.2658613             0.9385905        0.7049331       0.2634853
3       2.4477570             1.5596962        0.9923598       2.8800275
```



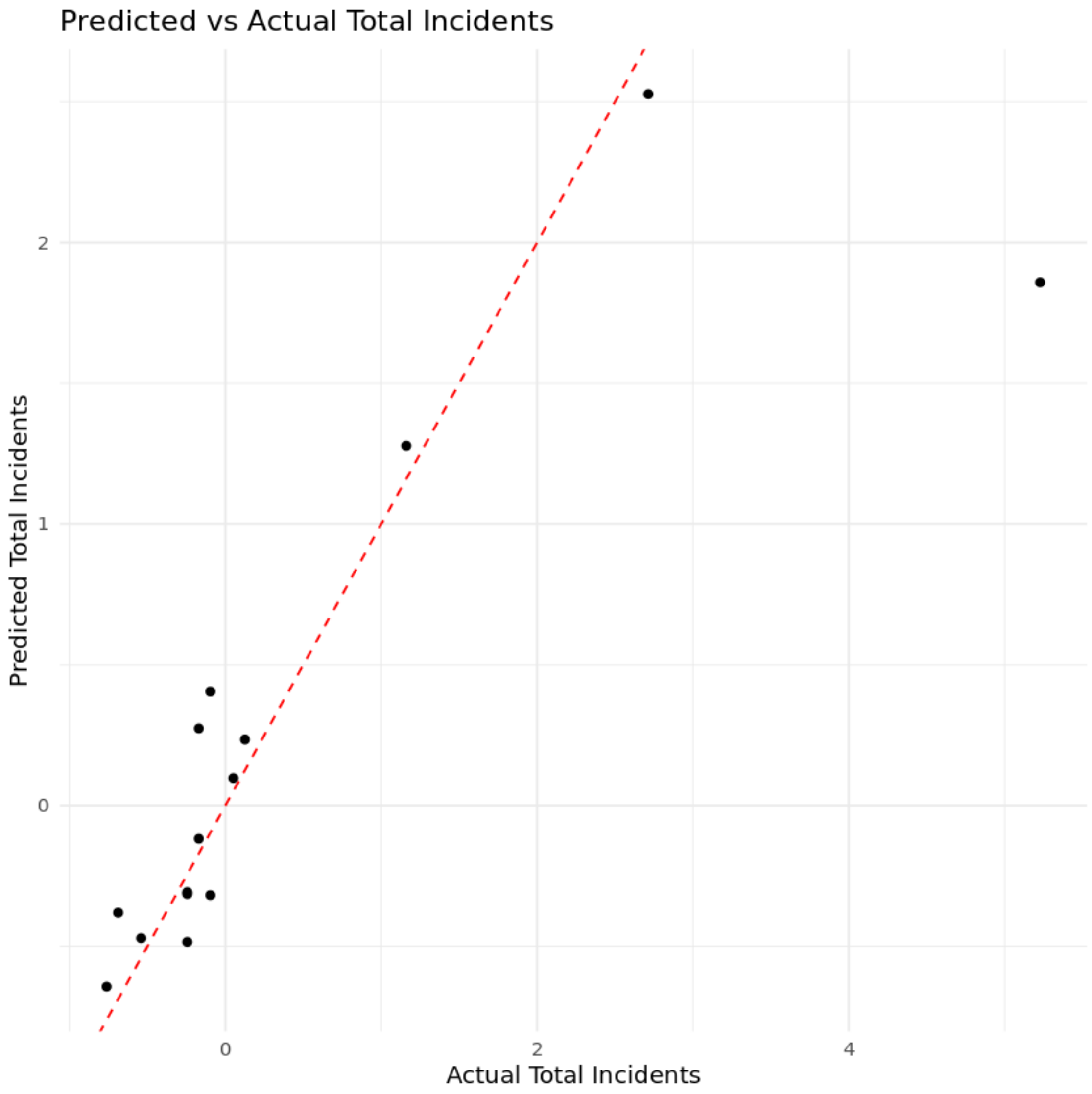
Analysis Method 3: Classification/Regression

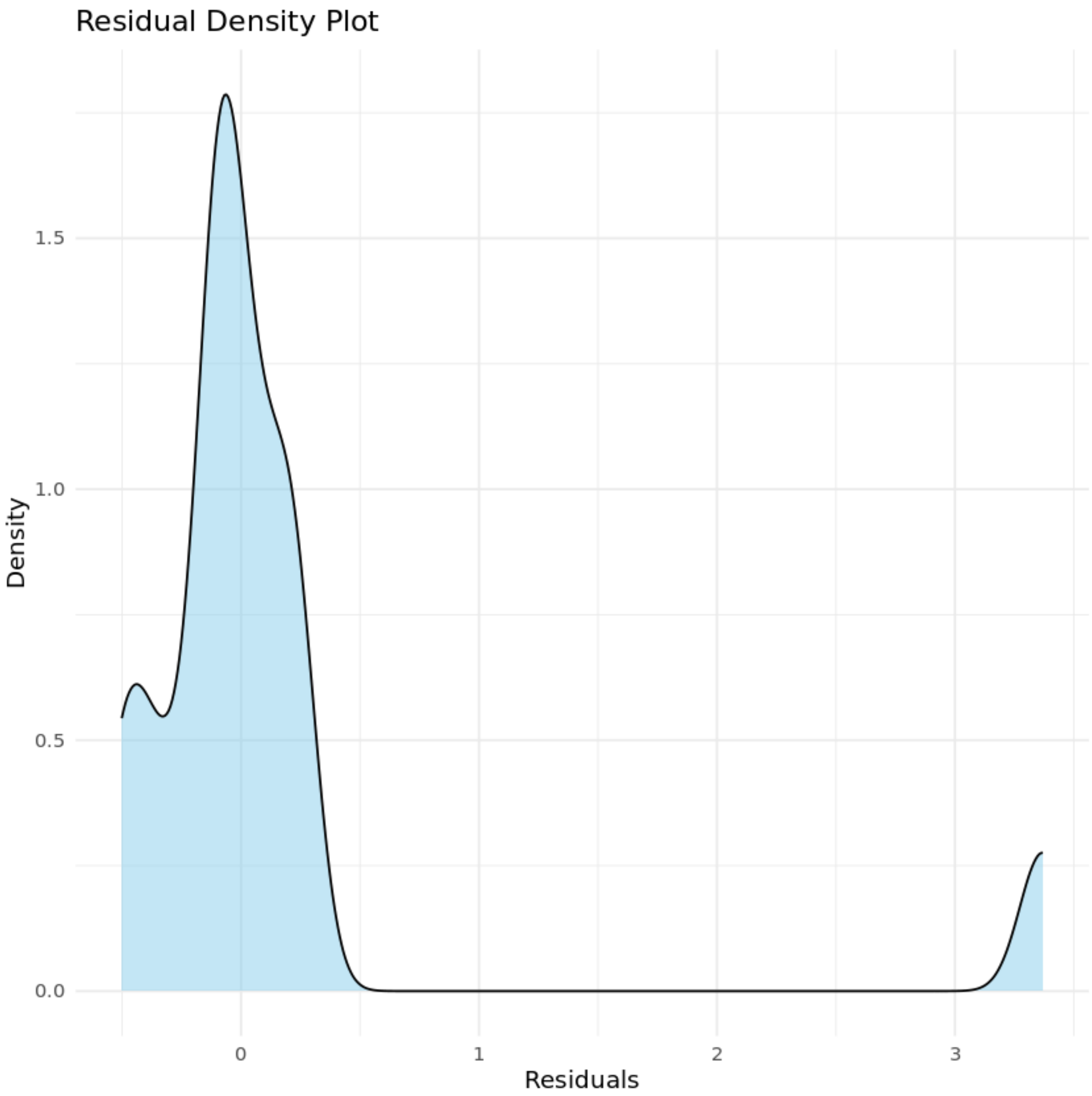
[24]:

```
d <- airline_numeric

glimpse(d)
summary(d)

set.seed(123)
train <- runif(nrow(d)) < 0.75
test <- !train

f <- total_incidents ~ avail_seat_km_per_week +
                       fatal_accidents_85_99 +
                       fatalities_85_99 +
                       fatal_accidents_00_14 +
                       fatalities_00_14

m <- lm(f, data = d %>% filter(train))
summary(m)

dx <- d %>% filter(test)
dx <- dx %>% mutate(total_incidents_pred = predict(m, dx))

ggplot(dx, aes(x = total_incidents, y = total_incidents_pred)) +
  geom_point() +
  geom_abline(slope = 1, intercept = 0, linetype="dashed", color="red") +
  labs(x = "Actual Total Incidents", y = "Predicted Total Incidents",
       title = "Predicted vs Actual Total Incidents") +
  theme_minimal()

ggplot(dx, aes(x = total_incidents - total_incidents_pred)) +
  geom_density(fill = "skyblue", alpha = 0.5) +
  labs(x = "Residuals", y = "Density", title = "Residual Density Plot") +
  theme_minimal()
```

```
Rows: 56
Columns: 8
$ avail_seat_km_per_week <dbl> -0.7259280, -0.1275826,
-0.6816394, -0.5375967,…
$ incidents_85_99        <dbl> -0.46925812, 6.23627861,
-0.10679668, -0.378642…
$ fatal_accidents_85_99  <dbl> -0.76145372, 4.13182264,
-0.76145372, -0.411933…
$ fatalities_85_99       <dbl> -0.76630896, 0.10627287,
-0.76630896, -0.330018…
$ incidents_00_14        <dbl> -0.90759530, 0.41254332,
-0.68757220, 0.1925202…
$ fatal_accidents_00_14  <dbl> -0.7694501, 0.3951230,
-0.7694501, -0.7694501, …
$ fatalities_00_14       <dbl> -0.49866599, 0.29175730,
-0.49866599, -0.498665…
$ total_incidents        <dbl> -0.68798457, 5.22789039,
-0.31824238, -0.244293…
```

```
 avail_seat_km_per_week incidents_85_99    fatal_accidents_85_99
 Min.   :-0.7679        Min.   :-0.65049   Min.   :-0.7615
 1st Qu.:-0.6214        1st Qu.:-0.46926   1st Qu.:-0.7615
 Median :-0.3970        Median :-0.28803   Median :-0.4119
 Mean   : 0.0000        Mean   : 0.00000   Mean   : 0.0000
 3rd Qu.: 0.3157        3rd Qu.: 0.07443   3rd Qu.: 0.2871
 Max.   : 3.9273        Max.   : 6.23628   Max.   : 4.1318
 fatalities_85_99  incidents_00_14   fatal_accidents_00_14 fatalities_00_14
 Min.   :-0.7663   Min.   :-0.9076   Min.   :-0.7695       Min.   :-0.4987
 1st Qu.:-0.7663   1st Qu.:-0.6876   1st Qu.:-0.7695       1st Qu.:-0.4987
 Median :-0.4357   Median :-0.2475   Median :-0.7695       Median :-0.4987
 Mean   : 0.0000   Mean   : 0.0000   Mean   : 0.0000       Mean   : 0.0000
 3rd Qu.: 0.4897   3rd Qu.: 0.2475   3rd Qu.: 0.3951       3rd Qu.: 0.2491
 Max.   : 2.8808   Max.   : 4.3730   Max.   : 2.7243       Max.   : 4.3247
 total_incidents
 Min.   :-0.83588
 1st Qu.:-0.54009
 Median :-0.24429
 Mean   : 0.00000
 3rd Qu.: 0.06999
 Max.   : 5.22789


Call:
lm(formula = f, data = d %>% filter(train))

Residuals:
     Min       1Q   Median       3Q      Max
-0.69534 -0.19062 -0.07417  0.12749  0.82468

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)           -0.04264    0.05525  -0.772  0.44540
avail_seat_km_per_week  0.18559    0.06571   2.824  0.00777 **
fatal_accidents_85_99   0.44669    0.13185   3.388  0.00175 **
fatalities_85_99      -0.02005    0.06732  -0.298  0.76755
fatal_accidents_00_14   0.27089    0.08881   3.050  0.00434 **
fatalities_00_14      -0.08698    0.07182  -1.211  0.23396
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.3282 on 35 degrees of freedom
Multiple R-squared:  0.7709,	Adjusted R-squared:  0.7381
F-statistic: 23.55 on 5 and 35 DF,  p-value: 2.678e-10
```


Predicted vs Actual Total Incidents
Predicted Total Incidents
Actual Total Incidents
2
1
0
0
2
4



High vs. Low Risk Prediction

[27]:

```
install.packages("glmnet")
library(glmnet)
```

```
Installing package into ‘/srv/rlibs’
(as ‘lib’ is unspecified)
```

[28]:

```
airline_scaled <- airline_scaled %>%
  mutate(high_risk = ifelse(class == "high", 1, 0))

set.seed(123)
```

```r
train_idx <- runif(nrow(airline_scaled)) < 0.75
train <- airline_scaled[train_idx, ]
test  <- airline_scaled[!train_idx, ]

predictors <- c(
  "avail_seat_km_per_week",
  "incidents_85_99",
  "fatal_accidents_85_99",
  "fatalities_85_99",
  "incidents_00_14",
  "fatal_accidents_00_14",
  "fatalities_00_14"
)

x_train <- as.matrix(train[, predictors])
y_train <- train$high_risk

x_test  <- as.matrix(test[, predictors])
y_test  <- test$high_risk

set.seed(123)
cv_fit <- cv.glmnet(
  x = x_train,
  y = y_train,
  family = "binomial",
  alpha = 1
)

plot(cv_fit)

best_lambda <- cv_fit$lambda.min
best_lambda

coef(cv_fit, s = "lambda.min")

pred_prob <- predict(cv_fit, newx = x_test, s = "lambda.min", type = "response")
pred_class <- ifelse(pred_prob > 0.5, 1, 0)

table(Predicted = pred_class, Actual = y_test)

mean(pred_class == y_test)

install.packages("pROC")
library(pROC)

roc_obj <- roc(y_test, as.numeric(pred_prob))
plot(roc_obj)
```

```
auc(roc_obj)
```

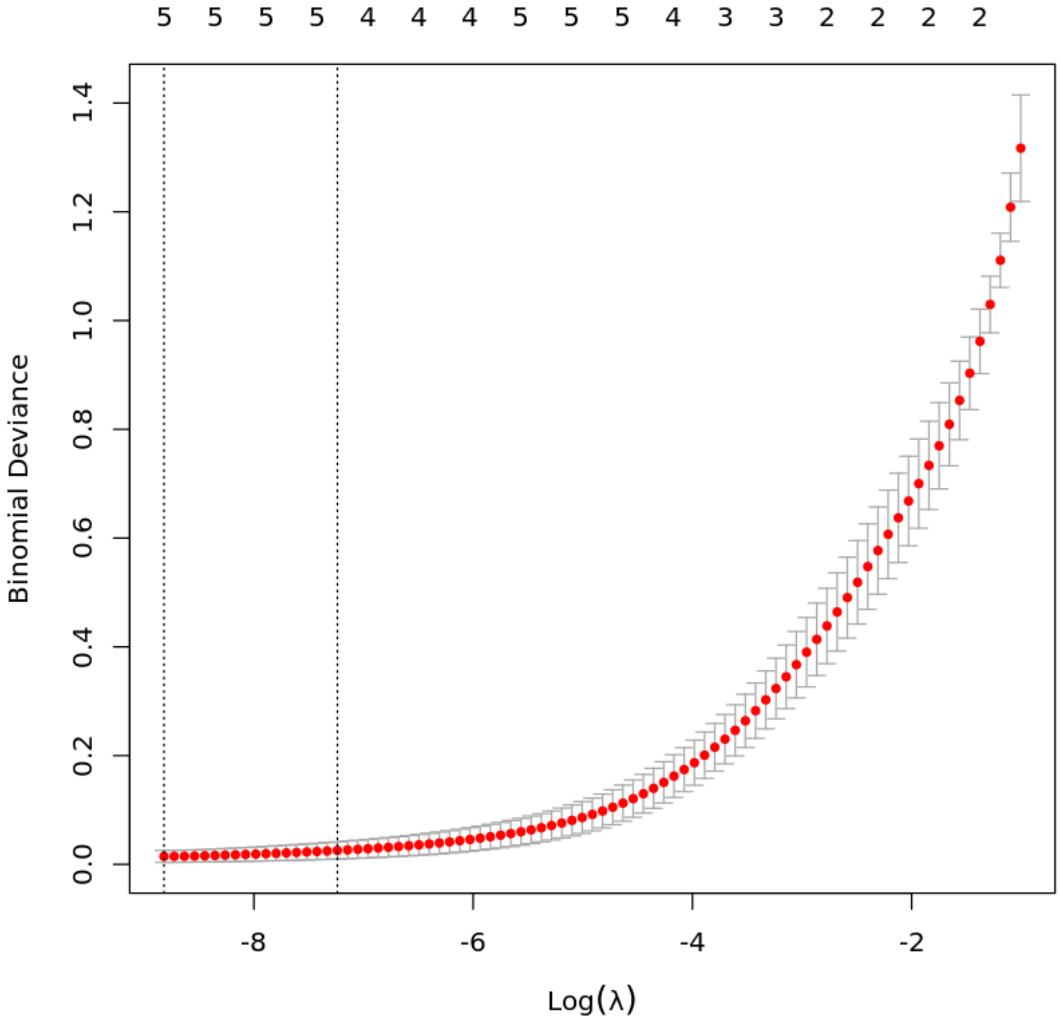
0.000147769023058982

```
8 x 1 sparse Matrix of class "dgCMatrix"
                               s1
(Intercept)            -0.7118349
avail_seat_km_per_week  0.8971479
incidents_85_99         1.7607994
fatal_accidents_85_99   .
fatalities_85_99       -3.0961270
incidents_00_14         .
fatal_accidents_00_14   0.1217560
fatalities_00_14       17.3776756
```

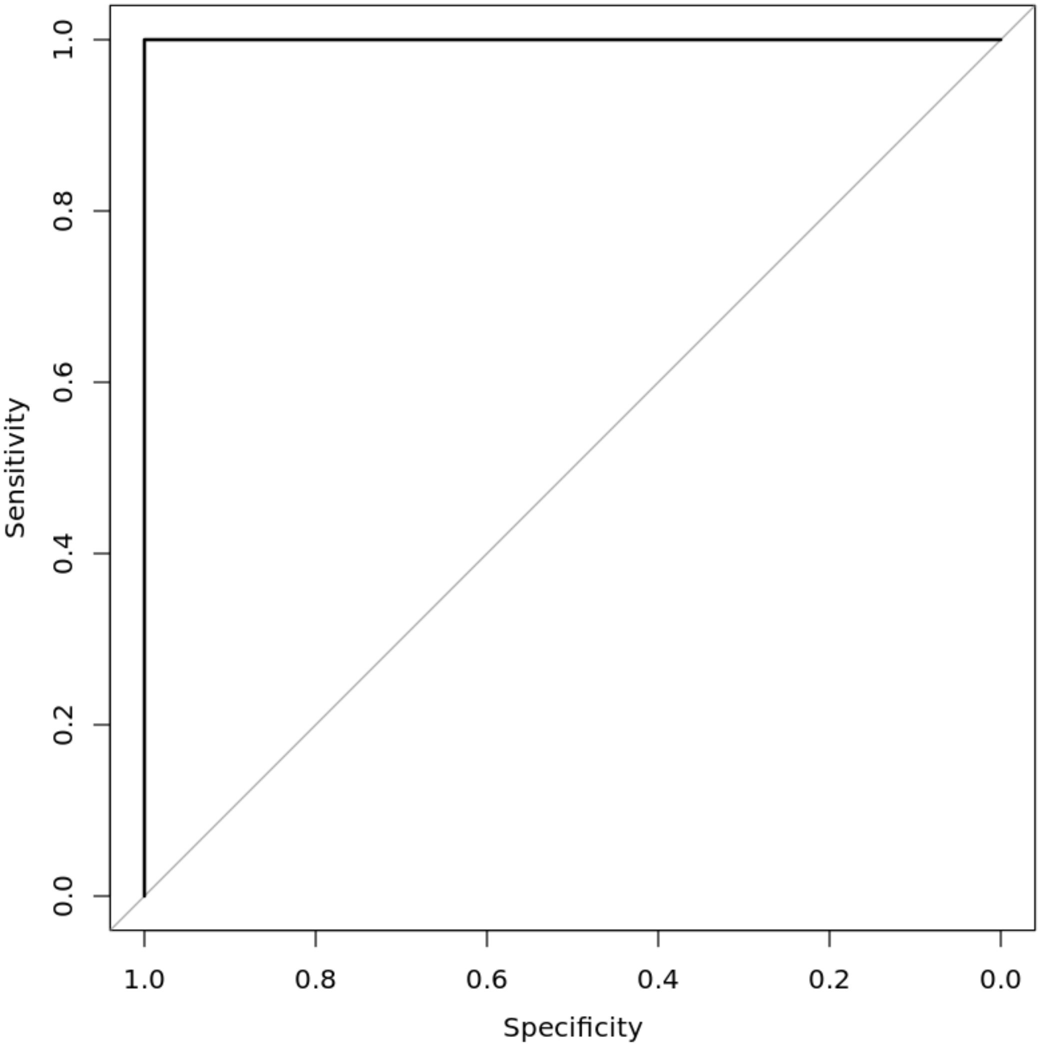
```
         Actual
Predicted  0  1
        0 13  1
        1  0  1
```

0.933333333333333

```
Installing package into ‘/srv/rlibs’
(as ‘lib’ is unspecified)

Setting levels: control = 0, case = 1

Setting direction: controls < cases
```


5
5
5
5
4
4
4
5
5
5
4
3
3
2
2
2
2
Binomial Deviance
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
-8
-6
-4
-2
Log(λ)

1


Sensitivity
1.0
0.8
0.6
0.4
0.2
0.0
Specificity
1.0
0.8
0.6
0.4
0.2
0.0