

Case Study: Flight Delays

Introduction and goals

This case study aims to perform quality assessment, regression and clustering on a dataset published by DOT's Bureau of Transportation Statistics containing information obtained in 2015 about the on-time performance of domestic flights operated by large air carriers.

To address different correlation metrics, two external datasets with passengers per airport and weather data is added.

Environment preparation

```
# loading required packages
packages <- c("ggplot2", "GGally", "corrplot", "scales", "gridExtra",
            "lubridate", "grid", "ggpubr", "RColorBrewer", "dplyr",
            "ggforce", "waffle", "reshape2", "cluster", "fpc", "NbClust",
            "data.table", "network", "ggraph", "factoextra")

# invisible to apply the require function without output messages
invisible(lapply(packages, require, character.only = T, quietly = T))
```

Data input

```
# setting file path once (easier to change for testing on multiple machines)
csv_path = "data/"
image_path = "images/"

# dataset imports into a data frame
airlines <- fread(paste(csv_path, "airlines.csv", sep=""))
airports <- fread(paste(csv_path, "airports.csv", sep=""))
flights <- fread(paste(csv_path, "flights.csv", sep=""))
passengers <- fread(paste(csv_path, "passengers-per-airport.csv", sep=""))
```

First considerations about input show in the raw dataset:

- 14 airlines;
- 322 airports;
- 5 819 079 flights.

This information needs to be subject of cleansing and quality checks.

Structure of Data and Quality Assessment

```
nrow(flights[complete.cases(flights), ])
```

```
## [1] 1063439
```

```
nrow(airlines[complete.cases(airlines), ])
```

```
## [1] 14
```

```
nrow(airports[complete.cases(airports), ])
```

```
## [1] 319
```

Only 20% of data is complete on flights: this is likely because in case of no delay there is NA, therefore to obtain a more comprehensive insight it is possible to check whether there are NA in the other columns (the first 23).

```
nrow(flights[complete.cases(flights[, 1:23]), ])
```

```
## [1] 5714008
```

This gives a better result. Now it is a good idea to zoom on the incomplete values and understand which columns they belong to.

```
# which columns actually have NA (or infinite)?
```

```
na_inf_airlines <- apply(airlines, 2, function(x) any(is.na(x) | is.infinite(x)))
```

```
# extraction of column names
```

```
# apply returns a named logical vector of which the true columns are extracted
names(na_inf_airlines[na_inf_airlines]) # null (nothing is missing)
```

```
## character(0)
```

```
na_inf_airports <- apply(airports, 2, function(x) any(is.na(x) | is.infinite(x)))
names(na_inf_airports[na_inf_airports])
```

```
## [1] "LATITUDE" "LONGITUDE"
```

```
na_inf_flights <- apply(flights, 2, function(x) any(is.na(x) | is.infinite(x)))
names(na_inf_flights[na_inf_flights]) # delay, departure, arrival
```

```
## [1] "DEPARTURE_TIME"      "DEPARTURE_DELAY"      "TAXI_OUT"
## [4] "WHEELS_OFF"           "SCHEDULED_TIME"       "ELAPSED_TIME"
## [7] "AIR_TIME"              "WHEELS_ON"            "TAXI_IN"
## [10] "ARRIVAL_TIME"         "ARRIVAL_DELAY"        "AIR_SYSTEM_DELAY"
## [13] "SECURITY_DELAY"        "AIRLINE_DELAY"        "LATE_AIRCRAFT_DELAY"
## [16] "WEATHER_DELAY"
```

The preliminary result on a first check on null values gives that the overall presence of complete information is good: airlines are all present, while only 3 airports are missing just latitude or longitude. Since the analysis does not concern spatial analysis of airports and the information can be obtained through external sources, all airports can be used.

Flights are concerned by the biggest amount of missing data: this is either due to inaccuracy, or (rather) to lack of flight delay (or specific kinds of delay).

More information on the weight of NA on flights needs to be therefore acquired. Since departure and arrival time are essential fields for analysis, all flights with NA must be removed.

Data Preprocessing

```
flights <- flights[complete.cases(flights$DEPARTURE_TIME)]
flights <- flights[complete.cases(flights$ARRIVAL_TIME)]
# 5 726 566
```

After completing assessment of null and zero values, it is necessary to perform an evaluation of the correctness of information.

Some flights have origin or destination airport not present in the dataset, hence they must be removed as well.

```
# removing incorrect IATA codes
flights <- flights[flights$ORIGIN_AIRPORT %in% airports$IATA_CODE]
flights <- flights[flights$DESTINATION_AIRPORT %in% airports$IATA_CODE]

nrow(flights)

## [1] 5242972
nrow(flights[flights$AIRLINE %in% airlines$IATA_CODE, ]) # same number (all correct)

## [1] 5242972
```

Exploratory analytics

After removing incorrect values, it is possible to begin analysing delays with simple statistics.

```
# checking how many flights left/arrived with delay
nrow(flights[complete.cases(flights$DEPARTURE_DELAY)]) 

## [1] 5242972
nrow(flights[complete.cases(flights$ARRIVAL_DELAY)]) 

## [1] 5231130
# further checking whether the dataset contains zero
nrow(flights[which(flights$DEPARTURE_DELAY == 0), ])

## [1] 299424
nrow(flights[which(flights$ARRIVAL_DELAY == 0)]) 

## [1] 115381
# checking negative values on departure and arrival delay
nrow(flights[which(flights$DEPARTURE_DELAY < 0), ])

## [1] 2967194
nrow(flights[which(flights$ARRIVAL_DELAY < 0)]) 

## [1] 3170103
nrow(flights[which(flights$DEPARTURE_DELAY < 0 & flights$ARRIVAL_DELAY < 0), ])

## [1] 2447206
```

Since research is focussed on flight delays, information about flights arriving on time or early can be removed.

```
# keeping flights that leave late or arrive late
flights <- flights[which(flights$DEPARTURE_DELAY > 0 | flights$ARRIVAL_DELAY > 0), ]
```

Considerations:

- Most flights leave and arrive with delay;
- A small part of the flights leaves or arrives in advance, but hardly ever both at the same time;
- It happens more often that a flight arrives with delay rather than leaves.

Counting the number of flights with delays per airline gives:

```
flights[ARRIVAL_DELAY > 0, .N, by = AIRLINE][order(-N)]
```

```

##      AIRLINE      N
## 1:      WN 440052
## 2:      DL 234999
## 3:      AA 229569
## 4:      OO 205771
## 5:      EV 197910
## 6:      UA 174497
## 7:      MQ  98767
## 8:      B6  93849
## 9:      US  76285
## 10:     NK  52634
## 11:     AS  52451
## 12:     F9  38684
## 13:     HA  27934
## 14:     VX  22244

```

Having available information related to months and days gives a good opportunity to perform time series analysis. An instance of that is weather delays, which is briefly shown below to be looked into in the further part of the work.

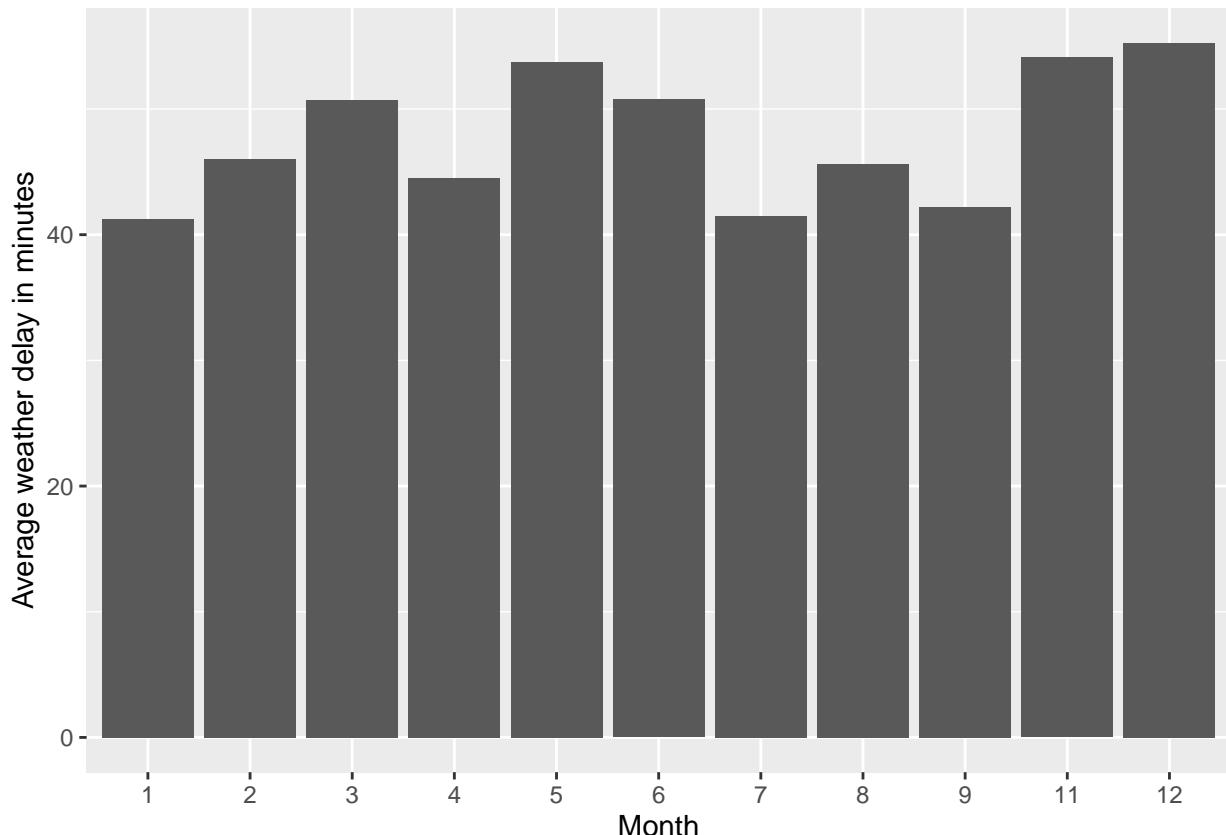
```

avg_delay_month <- flights[WEATHER_DELAY > 0, mean(WEATHER_DELAY), by = MONTH]

avg_delay_month$MONTH <- as.factor(avg_delay_month$MONTH)

ggplot(avg_delay_month, aes(x=MONTH, y=V1)) +
  labs(x="Month", y="Average weather delay in minutes") +
  geom_bar(stat="identity")

```



Mean and variance are also potentially interesting indicators to show anomalies and general trends.

```

# 5 airports with the biggest number of incoming flights
flights[, .N, by = DESTINATION_AIRPORT] [order(-N)] [1:10]

##      DESTINATION_AIRPORT      N
## 1:          ATL 143444
## 2:          ORD 130339
## 3:          LAX 106637
## 4:          DFW 102806
## 5:          DEN  95808
## 6:          SFO  76920
## 7:          PHX  71541
## 8:          IAH  69177
## 9:          LAS  65595
## 10:         MCO  54914

# mean and standard deviation of number of incoming flights
mean(flights[, .N, by = DESTINATION_AIRPORT]$N)

## [1] 7785.845
sd(flights[, .N, by = DESTINATION_AIRPORT]$N)

## [1] 18776.46

# same thing with outcoming flights
flights[, .N, by = ORIGIN_AIRPORT] [order(-N)] [1:10]

##      ORIGIN_AIRPORT      N
## 1:          ATL 158268
## 2:          ORD 145917
## 3:          DFW 117684
## 4:          DEN 106466
## 5:          LAX 103073
## 6:          IAH  77345
## 7:          PHX  75542
## 8:          SFO  73230
## 9:          LAS  68625
## 10:         SEA  56210

mean(flights[, .N, by = ORIGIN_AIRPORT]$N)

## [1] 7785.845
sd(flights[, .N, by = ORIGIN_AIRPORT]$N)

## [1] 20020.83

In presence of a null value, there are two feasible choices: replacing them with 0 (no delay) or ignoring them while computing statistics.

# mean arrival and departure delay (without NA)
mean(flights$DEPARTURE_DELAY, na.rm = TRUE)

## [1] 25.26682
mean(flights$ARRIVAL_DELAY, na.rm = TRUE)

## [1] 24.27084

```

```

# mean arrival and departure delay (assuming NA = 0)
flights0 <- copy(flights) # copy to avoid reference
flights0[is.na(flights0)] <- 0
mean(flights0$DEPARTURE_DELAY)

## [1] 25.26682
mean(flights0$ARRIVAL_DELAY)

## [1] 24.21317

```

The two results for mean and standard deviation are similar: to understand what dataset to use, it can be seen how many NA values get replaced in practice.

```

flights[(is.na(ARRIVAL_DELAY)), .N, ]

## [1] 5957
flights[(is.na(DEPARTURE_DELAY)), .N, ]

## [1] 0
flights[(DEPARTURE_DELAY == 0), .N, ]

## [1] 77883
flights[(ARRIVAL_DELAY == 0), .N, ]

## [1] 43716

```

The number of missing values is a very small percentage compared to the total amount of available data. Those, however, need to be taken into account and filtered while performing analysis and statistics on delays.

```

# mean arrival and departure delay for each airport
mean(flights$DEPARTURE_DELAY, na.rm = TRUE)

## [1] 25.26682
mean(flights$ARRIVAL_DELAY, na.rm = TRUE)

## [1] 24.27084
# mean arrival and departure delay for each airline
flights[, mean(DEPARTURE_DELAY), by = AIRLINE][order(-V1)]

##      AIRLINE      V1
## 1:      NK 32.948050
## 2:      F9 32.512666
## 3:      B6 29.833052
## 4:      MQ 29.702147
## 5:      UA 29.263996
## 6:      EV 27.357715
## 7:      OO 25.579702
## 8:      AA 25.439161
## 9:      WN 23.724913
## 10:     DL 23.245516
## 11:     VX 22.262415
## 12:     US 18.047741
## 13:     AS 14.880335
## 14:     HA  9.018944

```

```

flights[, mean(ARRIVAL_DELAY), by = AIRLINE] [order(-V1)]

##      AIRLINE V1
## 1:      US NA
## 2:      DL NA
## 3:      NK NA
## 4:      AA NA
## 5:      HA NA
## 6:      UA NA
## 7:      B6 NA
## 8:      OO NA
## 9:      EV NA
## 10:     F9 NA
## 11:     WN NA
## 12:     AS NA
## 13:     MQ NA
## 14:     VX NA

# airlines with their number of delayed arrivals
flights[(DEPARTURE_DELAY > 0), .N, by = AIRLINE] [order(-N)]

##      AIRLINE      N
## 1:      WN 526522
## 2:      DL 263322
## 3:      UA 238964
## 4:      AA 223528
## 5:      OO 159662
## 6:      EV 158465
## 7:      B6 93615
## 8:      MQ 88679
## 9:      US 62418
## 10:     NK 48402
## 11:     AS 40291
## 12:     F9 32632
## 13:     VX 21416
## 14:     HA 18438

flights[(ARRIVAL_DELAY > 0), .N, by = AIRLINE] [order(-N)]

##      AIRLINE      N
## 1:      WN 440052
## 2:      DL 234999
## 3:      AA 229569
## 4:      OO 205771
## 5:      EV 197910
## 6:      UA 174497
## 7:      MQ 98767
## 8:      B6 93849
## 9:      US 76285
## 10:     NK 52634
## 11:     AS 52451
## 12:     F9 38684
## 13:     HA 27934
## 14:     VX 22244

```

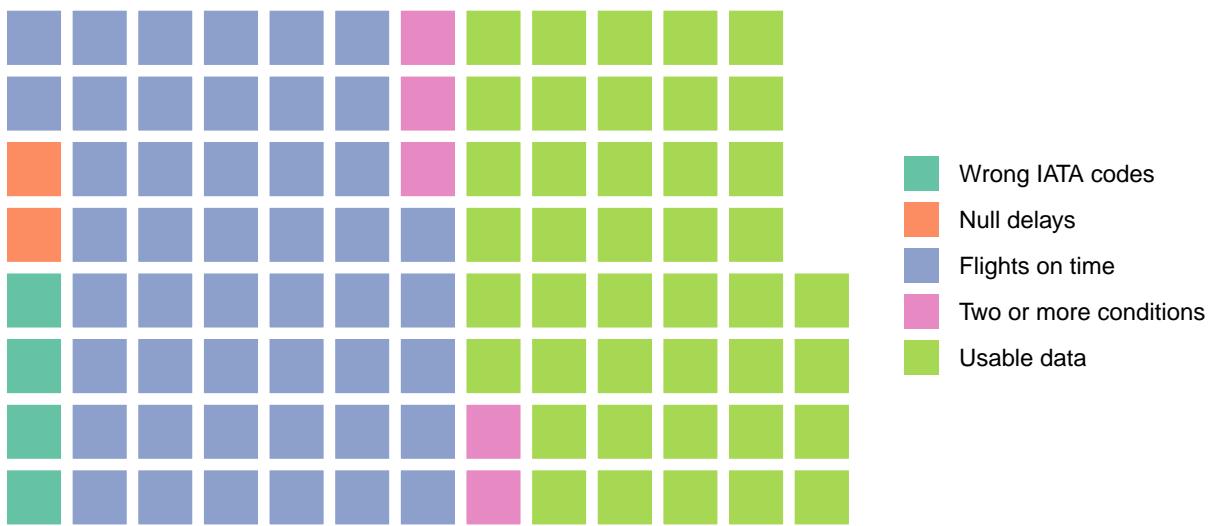
```

# wrapping up and plotting excluded values
# 486 165 incorrect IATA codes
# 105 071 null arrival or departure delays
# 3 020 210 irrelevant delays (flights leaving and arriving on time)
# around 300 000 rows falling in two or more of these conditions

values <- c(192713, 101784, 2730045, 293452, 2501085)
labels <- c("Wrong IATA codes" = 4, "Null delays" = 2, "Flights on time" = 47, "Two or more conditions" = 1)

# data scaled to %
waffle(labels, rows = 8)

```



After performing the first general analysis, it is possible to begin with more detailed results.

Map of all Airports in the U.S. with number of flights as weight for their connections

[@Axel Map here (+ maybe description)]

Network of U.S. Airports that highlights centrality etc.

[@Axel Network here (+ maybe description)]

Correlation between size of an airport and average delay of flights

Passengers data set

The data set for all airports in the U.S. was collected from the Federal Aviation Administration. It includes the passenger count for each airport in the U.S. in 2015.

First, the data set is read and briefly analysed for all airports in the U.S (“passenger-per-airport.csv”). There are 9 airports with no passengers data found, when combining the passengers data set with the original data set. Cross-checking with Wikipedia, none of them is in the top 60 (2017/2018) of U.S. airports by passengers boarding count. This means all missing airports are smaller airports, which could be expected.

```

# yearly passengers per airport
passengers <- fread(paste(csv_path, "passenger-per-airport.csv", sep=""))

```

```

head(passengers)

##      Rank RO ST Locid          City                  Airport Name
## 1:     1 SO GA  ATL  Atlanta Hartsfield - Jackson Atlanta International
## 2:     2 WP CA  LAX  Los Angeles                      Los Angeles International
## 3:     3 GL IL  ORD  Chicago                      Chicago O'Hare International
## 4:     4 SW TX  DFW  Fort Worth  Dallas-Fort Worth International
## 5:     5 EA NY  JFK  New York  John F Kennedy International
## 6:     6 NM CO  DEN  Denver  Denver International
##   S/L Hub CY 15 Enplanements CY 14 Enplanements % Change
## 1: P   L        49,340,732       46,604,273    5.87%
## 2: P   L        36,351,272       34,314,197    5.94%
## 3: P   L        36,305,668       33,843,426    7.28%
## 4: P   L        31,589,839       30,804,567    2.55%
## 5: P   L        27,782,369       26,244,928    5.86%
## 6: P   L        26,280,043       26,000,591    1.07%

pass_small <- passengers[,c(4,9)]
setnames(pass_small, "Locid", "IATA_CODE")
setnames(pass_small, "CY 15 Enplanements", "passengers_count")
pass_small[, passengers_count := as.numeric(gsub(", ", "", passengers_count))]

airports_pass <- merge(airports, pass_small, by="IATA_CODE", all.x = TRUE)

# checking for NAs
# result: for some airports there is no passengers_count and for some no lat/long data
airports_pass[!complete.cases(airports_pass)]
```

	IATA_CODE	AIRPORT
## 1:	ADK	Adak Airport
## 2:	CLD	McClellan-Palomar Airport
## 3:	CNY	Canyonlands Field
## 4:	ECP	Northwest Florida Beaches International Airport
## 5:	FCA	Glacier Park International Airport
## 6:	MQT	Sawyer International Airport
## 7:	PBG	Plattsburgh International Airport
## 8:	SCE	University Park Airport
## 9:	UST	Northeast Florida Regional Airport (St. Augustine Airport)
## 10:	VEL	Valdez Airport
## 11:	YUM	Yuma International Airport
	CITY STATE COUNTRY LATITUDE LONGITUDE	passengers_count
## 1:	Adak AK USA 51.87796 -176.64603	NA
## 2:	San Diego CA USA 33.12723 -117.27873	NA
## 3:	Moab UT USA 38.75496 -109.75484	NA
## 4:	Panama City FL USA NA NA	428704
## 5:	Kalispell MT USA 48.31140 -114.25507	NA
## 6:	Marquette MI USA 46.35364 -87.39536	NA
## 7:	Plattsburgh NY USA NA NA	131600
## 8:	State College PA USA 40.85121 -77.84630	NA
## 9:	St. Augustine FL USA NA NA	NA
## 10:	Vernal UT USA 40.44090 -109.50992	NA
## 11:	Yuma AZ USA 32.65658 -114.60597	NA

```

sum(!complete.cases(airports_pass))

```

```

## [1] 11
nrow(airports)

## [1] 322
# deleting all airports that don't have a passenger count
nrow(airports_pass)

## [1] 322
airports_pass <- airports_pass[complete.cases(airports_pass[,passengers_count])]

Next, it is a good idea to visualize some interesting graphs with the passengers data, including correlation. We start with looking at how the passengers data looks like:

colnames(airports_pass)

## [1] "IATA_CODE"           "AIRPORT"            "CITY"
## [4] "STATE"               "COUNTRY"            "LATITUDE"
## [7] "LONGITUDE"           "passengers_count"

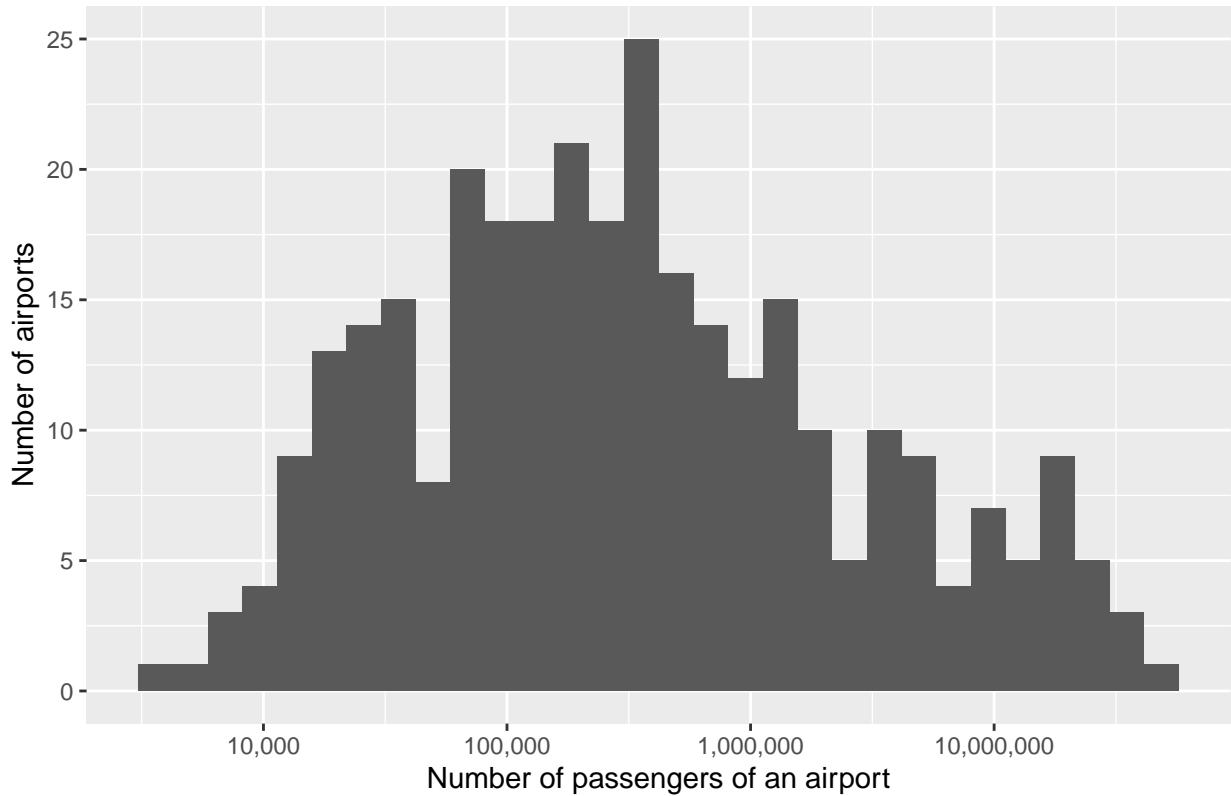
head(airports_pass[order(passengers_count)])

##      IATA_CODE                      AIRPORT
## 1:    PUB          Pueblo Memorial Airport
## 2: CEC Del Norte County Airport (Jack McNamara Field)
## 3:   JMS        Jamestown Regional Airport
## 4:   DVL        Devils Lake Regional Airport
## 5:   WYS       Westerly State Airport
## 6:   HYS        Hays Regional Airport
##             CITY STATE COUNTRY LATITUDE LONGITUDE passengers_count
## 1:      Pueblo CO     USA 38.28909 -104.49657      3674
## 2: Crescent City CA     USA 41.78016 -124.23653      4915
## 3:    Jamestown ND     USA 46.92972 -98.67820      6086
## 4:    Devils Lake ND     USA 48.11425 -98.90878      6180
## 5: West Yellowstone MT     USA 44.68840 -111.11764      7796
## 6:        Hays KS     USA 38.84494 -99.27403      8470

ggplot(airports_pass, aes(x=passengers_count,y=)) +
  geom_histogram() +
  scale_x_log10(breaks=c(1000, 10000, 100000, 1000000, 10000000), labels = scales::comma) +
  labs(x = 'Number of passengers of an airport',
       y = 'Number of airports',
       title = 'Histogram of passengers per airport')

```

Histogram of passengers per airport



Then we do some data manipulation for later use, e.g. calculate how many flights start at an airport.

```
# extracting the relevant columns of flights
flights_small <- flights[,.(ORIGIN_AIRPORT, DESTINATION_AIRPORT, DEPARTURE_DELAY, ARRIVAL_DELAY)]  
  
# calculating number of flights per airport
origin_airport_numflights <- flights_small[,.(FLIGHTS_COUNT = .N), by = ORIGIN_AIRPORT]  
  
# calculating mean delay per airport
origin_airport_delay <- flights_small[, .(mean_D_DELAY = mean(DEPARTURE_DELAY,na.rm=T)), by = ORIGIN_AIRPORT]  
  
# calculating mean delay per airport, ignoring negative delay (flight left too early)
origin_airport_delay_pos <- flights_small[DEPARTURE_DELAY > 0,
                                         .(mean_D_DELAY = mean(DEPARTURE_DELAY,na.rm=T)),
                                         by = ORIGIN_AIRPORT]  
  
# Merge the number of flights with passenger count per airport
origin_airport_numflights_pass <- merge(origin_airport_numflights,airports_pass,by.x="ORIGIN_AIRPORT",by.y="IATA_CODE")
origin_airport_numflights_pass <- origin_airport_numflights_pass[,c("ORIGIN_AIRPORT", "FLIGHTS_COUNT", "PASSENGERS")]
origin_airport_numflights_pass <- origin_airport_numflights_pass[,pass_per_flight := passengers_count/FLIGHTS_COUNT]  
  
# merge the delay with the passengers count per airport
origin_airport_delay_pass <- merge(origin_airport_delay, airports_pass, by.x="ORIGIN_AIRPORT", by.y="IATA_CODE")
origin_airport_delay_pos_pass <- merge(origin_airport_delay_pos, airports_pass, by.x="ORIGIN_AIRPORT", by.y="IATA_CODE")
```

The 20 biggest airports in the U.S.:

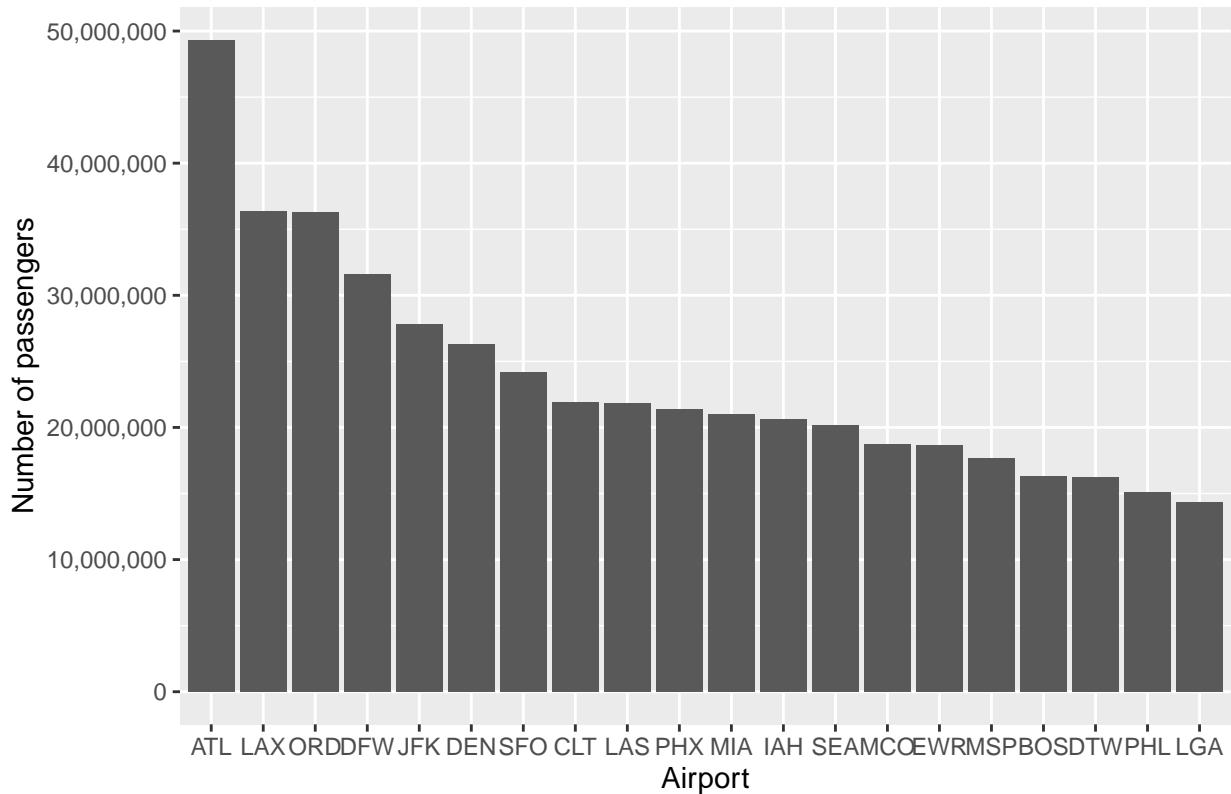
```

# order airports by number of passengers in 2015
airports_pass_ordered <- airports_pass[order(-passengers_count)]


# plot 20 biggest airports in the U.S.
ggplot(airports_pass_ordered[1:20], aes(reorder(IATA_CODE,-passengers_count),passengers_count)) +
  geom_bar(stat='identity') +
  labs(y = "Number of passengers",
       x = "Airport",
       title = "20 biggest airports in the U.S. by passengers") +
  scale_y_continuous(labels = scales::comma)

```

20 biggest airports in the U.S. by passengers



Correlation between number of passengers and total number of flights starting at an airport

```

str(origin_airport_numflights_pass)

## Classes 'data.table' and 'data.frame': 313 obs. of 4 variables:
## $ ORIGIN_AIRPORT : chr  "ABE" "ABI" "ABQ" "ABR" ...
## $ FLIGHTS_COUNT   : int  954 763 8666 257 326 222 522 512 1666 171 ...
## $ passengers_count: num  320544 86000 2323883 27595 33949 ...
## $ pass_per_flight : num  336 113 268 107 104 ...
## - attr(*, ".internal.selfref")=<externalptr>
## - attr(*, "sorted")= chr "ORIGIN_AIRPORT"

ggplot(origin_airport_numflights_pass, aes(x=passengers_count, y=FLIGHTS_COUNT)) +
  geom_point() +
  annotate("text", x=1420500, y=450, label="GUM") + # 334 flights

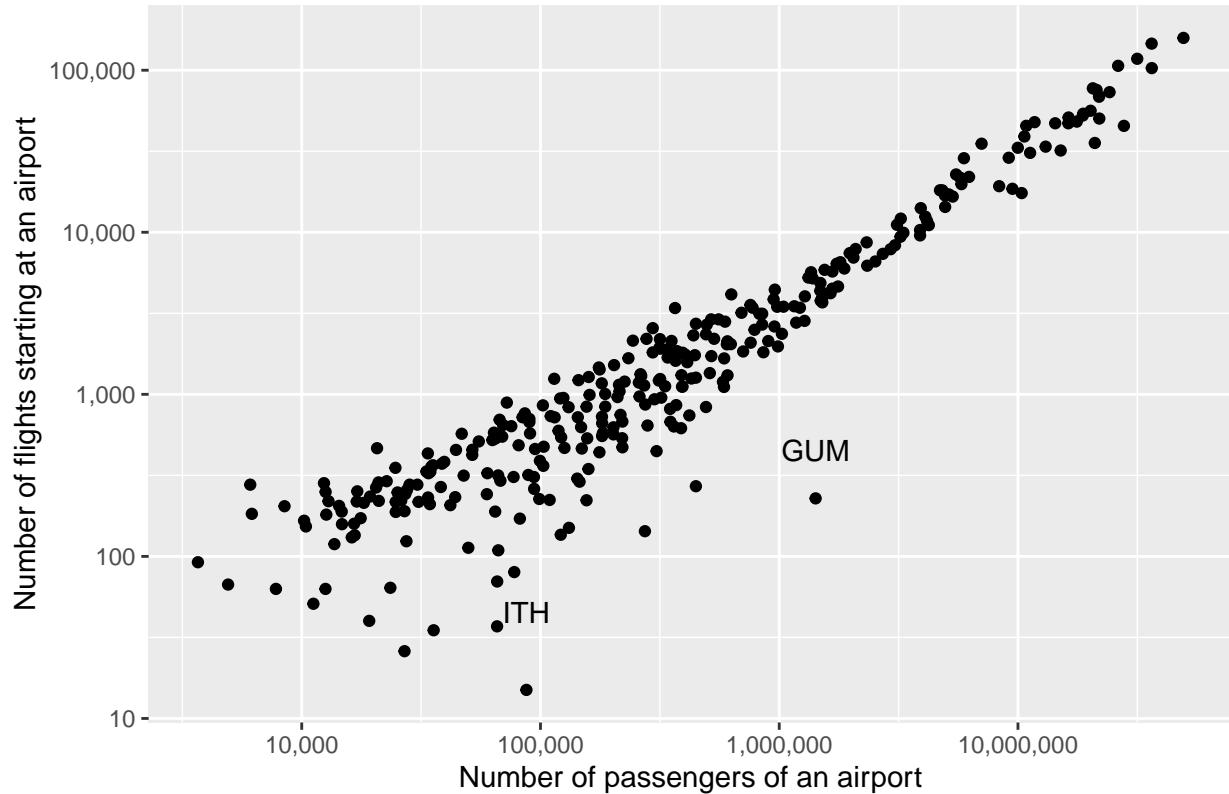
```

```

annotate("text", x=87321, y=45, label="ITH") +      # 34 flights
scale_x_log10(labels = scales::comma) +
scale_y_log10(labels = scales::comma) +
labs(x = "Number of passengers of an airport",
y = "Number of flights starting at an airport",
title = "Some outliers for passengers per flight")

```

Some outliers for passengers per flight



The airports “GUM” (Guam International Airport) and “ITH” (Ithaca Tompkins Regional Airport) look interesting because they have not enough flights for their number of passengers.

```
origin_airport_numflights_pass[ORIGIN_AIRPORT == "ITH" | ORIGIN_AIRPORT == "GUM"]
```

```

##   ORIGIN_AIRPORT FLIGHTS_COUNT passengers_count pass_per_flight
## 1:      GUM           228        1420500     6230.263
## 2:      ITH            15         87321      5821.400

airports[IATA_CODE == "ITH" | IATA_CODE == "GUM"]

##   IATA_CODE          AIRPORT CITY STATE COUNTRY
## 1:      GUM  Guam International Airport Agana    GU    USA
## 2:      ITH Ithaca Tompkins Regional Airport Ithaca    NY    USA
##   LATITUDE LONGITUDE
## 1: 13.48345 -144.79598
## 2: 42.49103   -76.45844

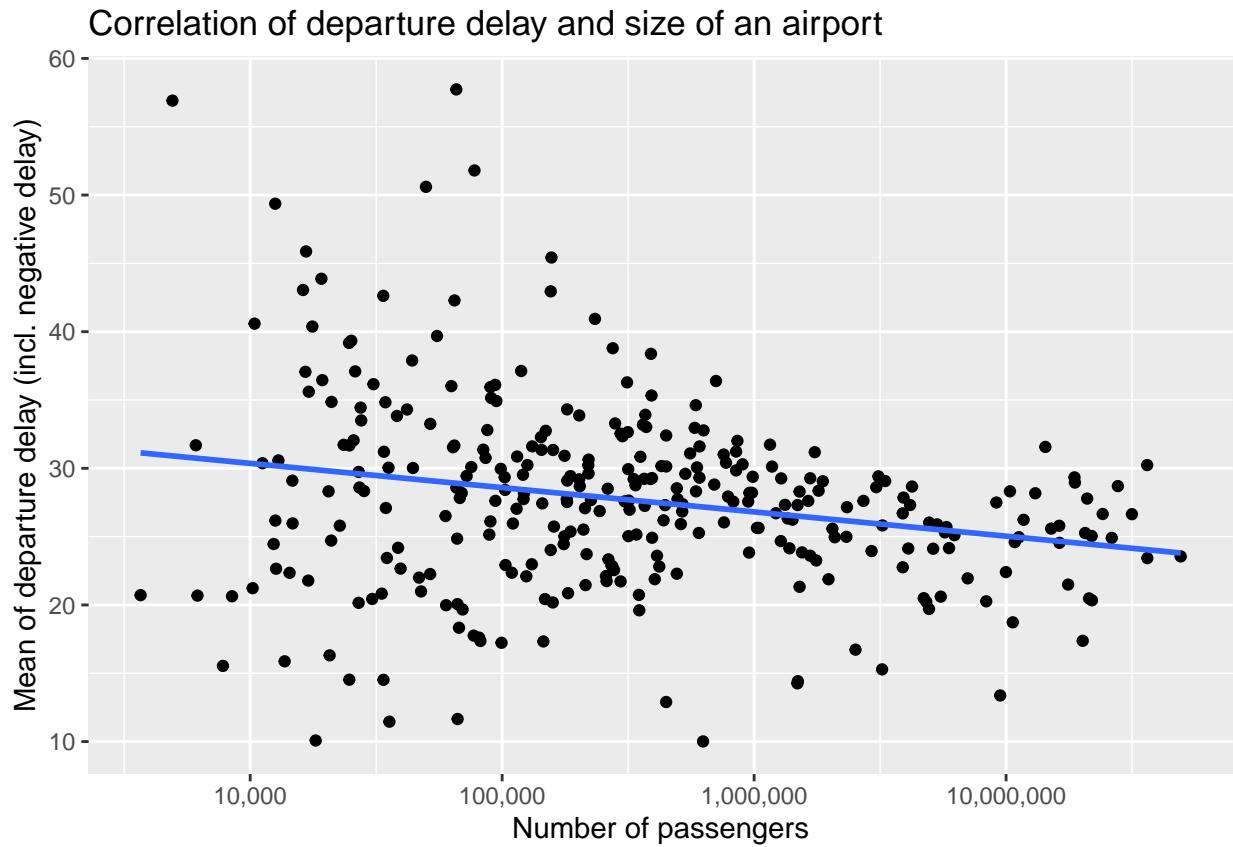
```

Correlation between number of passengers and mean/average delay of flights

When including negative delay (meaning the flight started early) only a small positive correlation between the number of passengers and the mean departure delay can be seen. But when only including positive delay

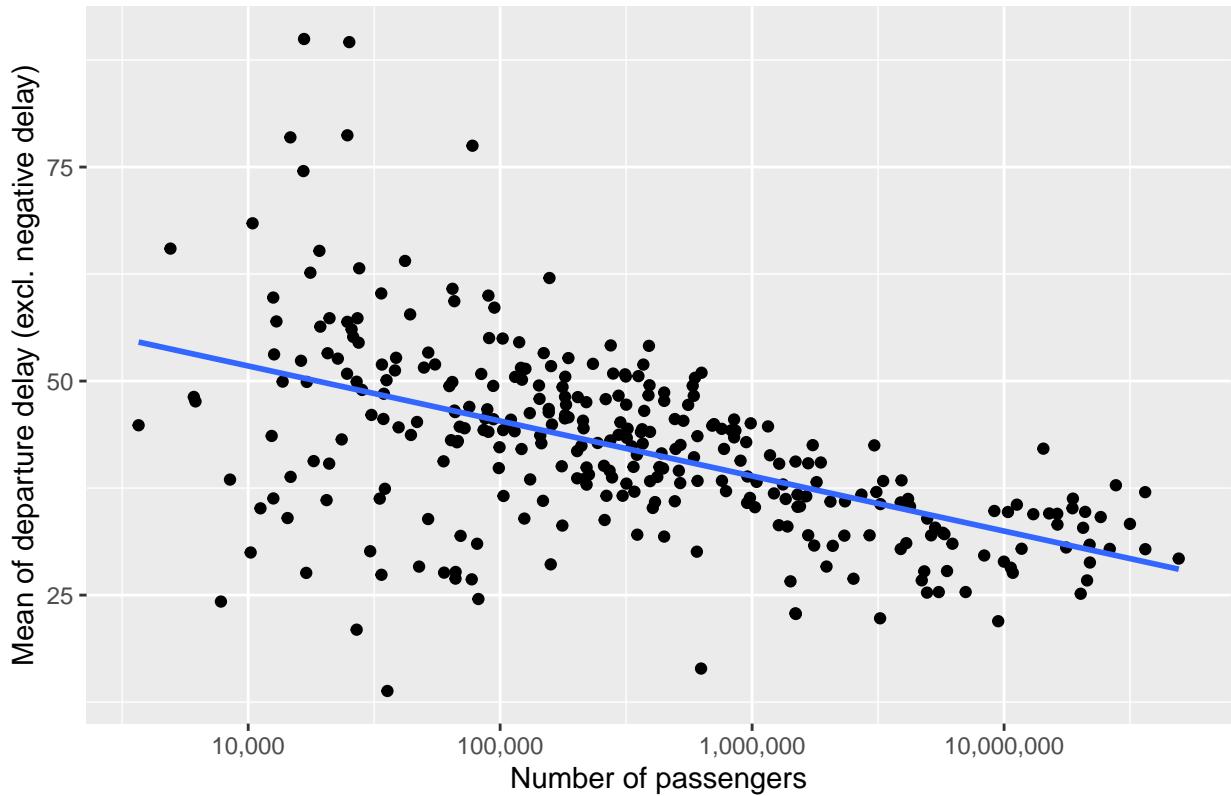
(meaning real delay, the flight started too late) a stronger negative correlation can be seen in the data. It can be argued that including only positive delay is the better metric, because the goal is to see when flights are delayed and not when they leave early.

```
ggplot(origin_airport_delay_pass, aes(passengers_count,mean_D_DELAY)) +
  geom_point() +
  geom_smooth(method = "lm", se=F) +
  scale_x_log10(labels = scales::comma) +
  labs(x = 'Number of passengers',
       y = 'Mean of departure delay (incl. negative delay)',
       title = 'Correlation of departure delay and size of an airport')
```



```
ggplot(origin_airport_delay_pos_pass, aes(passengers_count,mean_D_DELAY)) +
  geom_point() +
  geom_smooth(method = "lm", se=F) +
  scale_x_log10(labels = scales::comma) +
  labs(x = 'Number of passengers',
       y = 'Mean of departure delay (excl. negative delay)',
       title = 'Correlation of departure delay and size of an airport')
```

Correlation of departure delay and size of an airport



Correlation between weather data and delay, in Chicago as an example

Correlation between weather delay and departure delay or flight time delay

To find out if the weather delay caused by the weather of departure airports or the weather of arrival airports, we calculate the correlation between weather delay and departure delay, and the correlation between weather delay and flight time delay.

```
# delete cancelled and diverted flights
flights1 <- subset(flights0, CANCELLED == 0 & DIVERTED == 0)

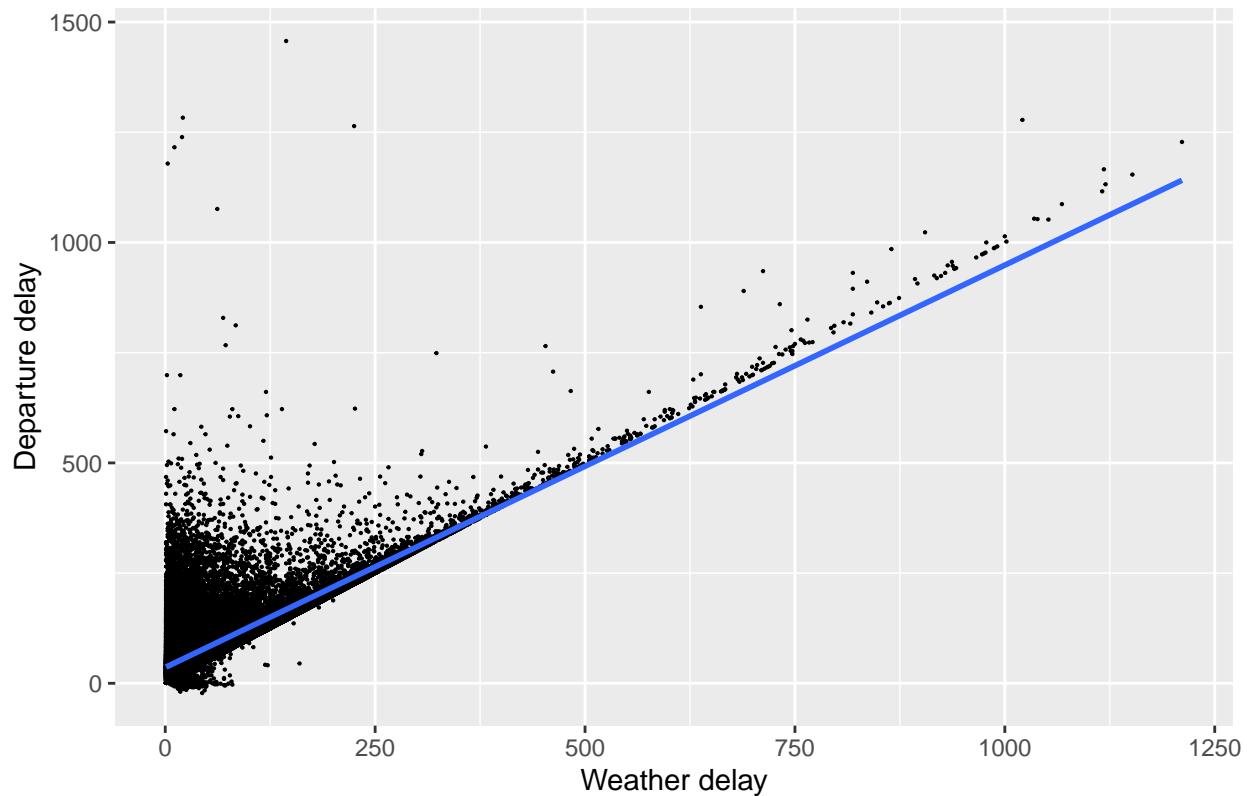
# plotting departure delay caused by weather
flights_weatherdly <- flights1[flights1$WEATHER_DELAY > 0]

cor(flights_weatherdly$DEPARTURE_DELAY, flights_weatherdly$WEATHER_DELAY)

## [1] 0.7579244

ggplot(flights_weatherdly,
       aes(flights_weatherdly$WEATHER_DELAY, flights_weatherdly$DEPARTURE_DELAY)) +
  geom_point(size=0.1) +
  geom_smooth(method = "lm", se=F) +
  labs(x = 'Weather delay',
       y = 'Departure delay',
       title = 'Departure delay caused by weather')
```

Departure delay caused by weather



Correlation between departure delay and weather delay is 0.75. we can see a high correlate through the scatter plot.

We calculate the flight time delay to measure the weather delay caused by bad weather of arrival airports.

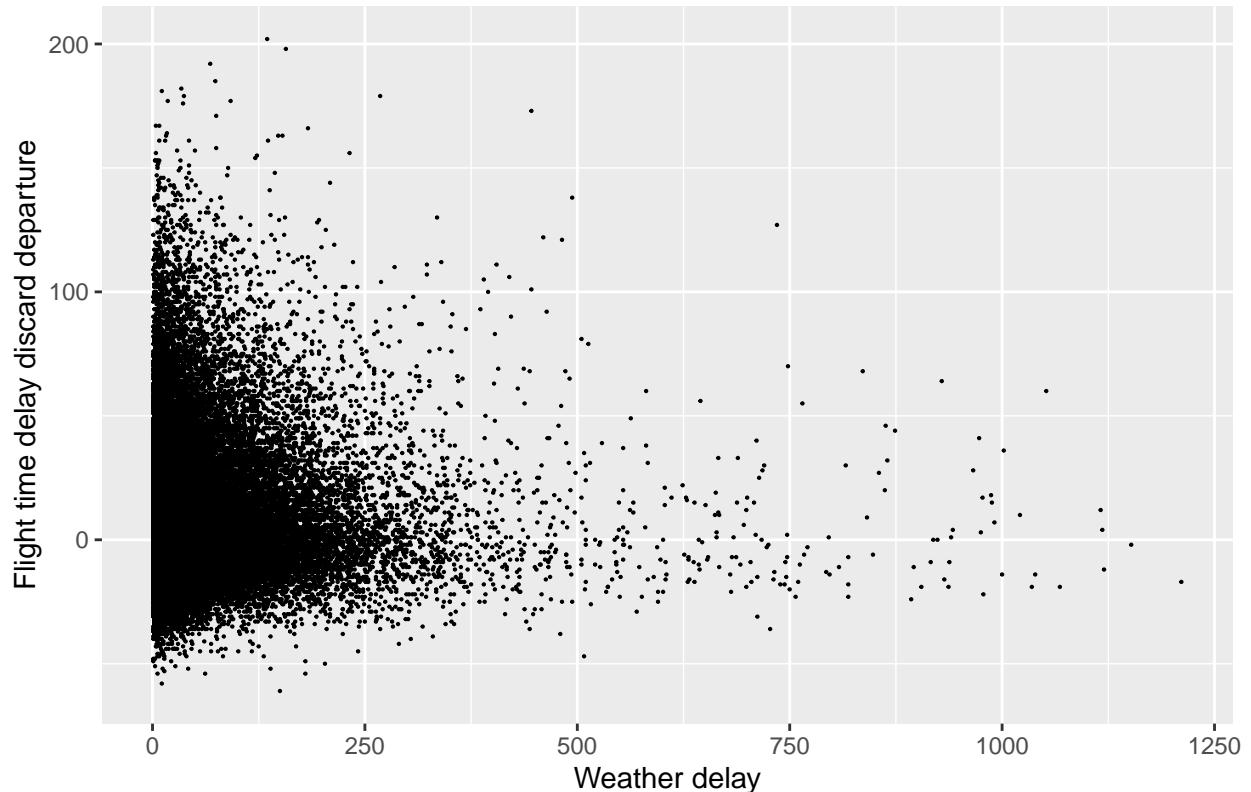
```
# calculating flight time delay
flights_weatherdly$FLIGHTTIME_DELAY <- flights_weatherdly$ARRIVAL_DELAY -
  flights_weatherdly$DEPARTURE_DELAY

# plotting flight time daley cause by wheather
cor(flights_weatherdly$FLIGHTTIME_DELAY, flights_weatherdly$WEATHER_DELAY)

## [1] 0.01234837

ggplot(flights_weatherdly,
  aes(flights_weatherdly$WEATHER_DELAY, flights_weatherdly$FLIGHTTIME_DELAY)) +
  geom_point(size=0.1) +
  labs(x = 'Weather delay',
       y = 'Flight time delay discard departure',
       title = 'Flight time delay caused by weather')
```

Flight time delay caused by weather



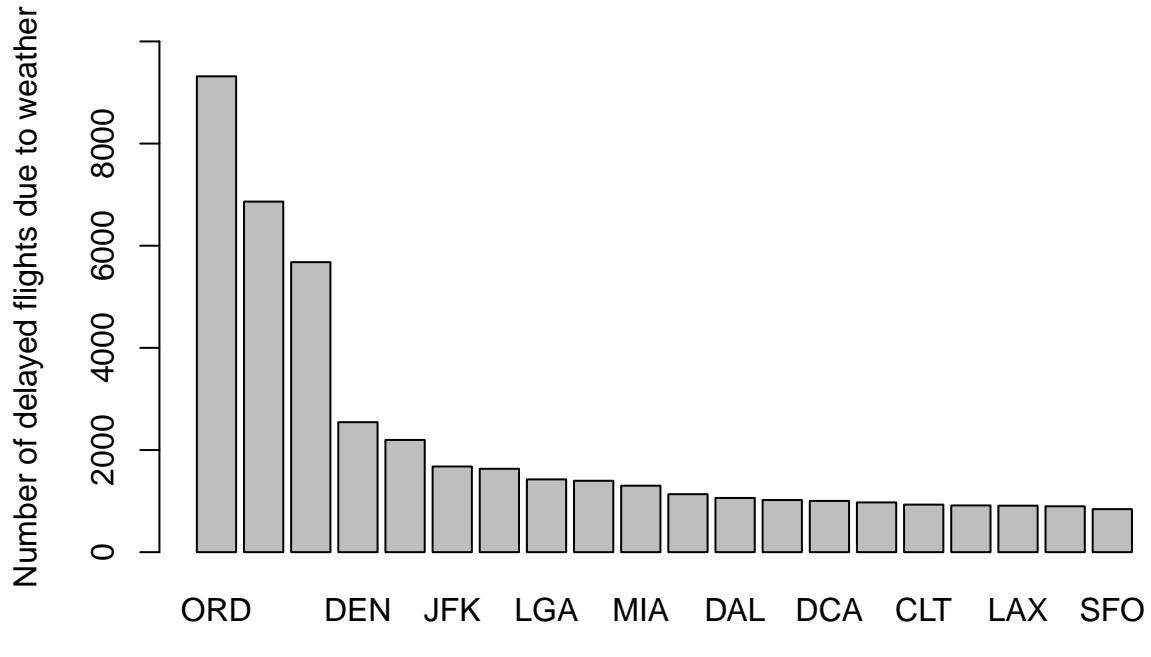
Correlation between flight time delay and weather delay is close to 0. Since the weather of arrival airports has a slight effect on weather delays, we can simply look at the weather of departure airports.

##Find the airport with the most weather delayed flights After having a general assessment of how weather delay behaves, it is possible to zoom on specific airports.

```
# finding worst wheater airport
org_airport <- table(flights_weatherdly$ORIGIN_AIRPORT)

airport_sort <- sort(org_airport, decreasing = T)
barplot(airport_sort[1:20],
       xlab="Airport",
       ylab="Number of delayed flights due to weather",
       main="Top 20 airports with the most flights delayed due to weather",
       ylim=c(0, 10000))
```

Top 20 airports with the most flights delayed due to weather



The airport with the biggest weather delay is ORD (Chicago O'Hare). Since daily weather data is publicly available, weather delay can be crossed with weather during the year.

The daily weather data set for Chicago O'Hare international airport was collected from wunderground.com. It recorded daily weather of Chicago O'Hare international airport including temperature, dew point, humidity, wind speed, pressure, and precipitation.

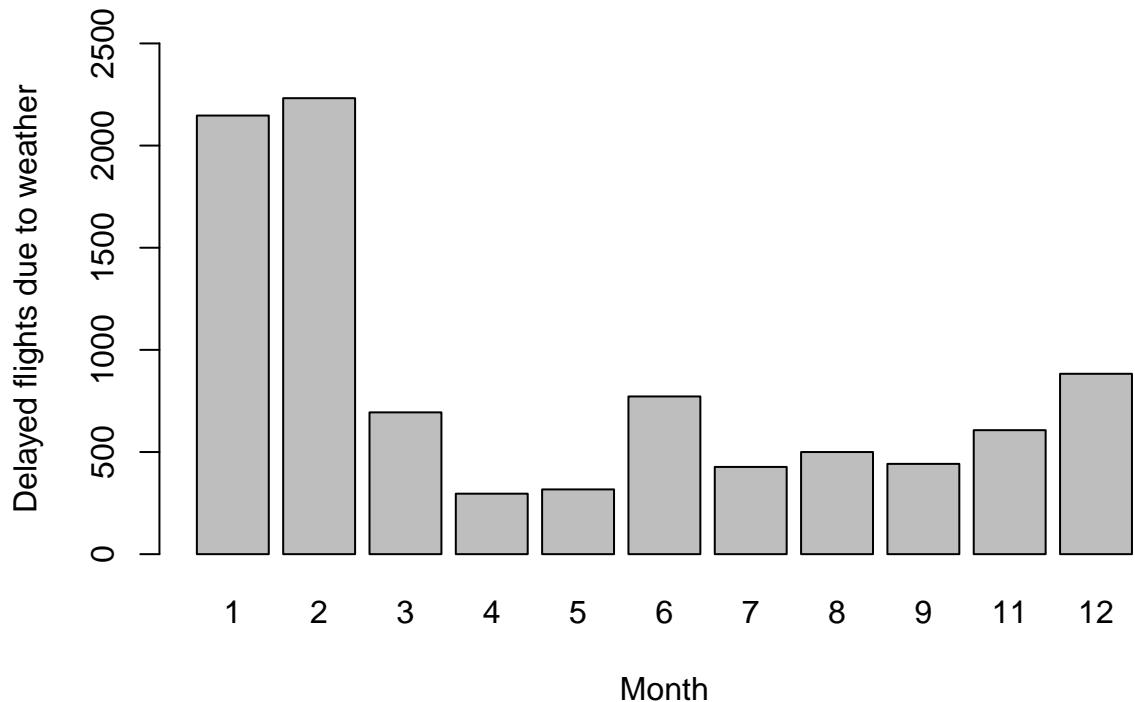
```
# importing daily ORD weather
ORD_weather <- fread(paste(csv_path, "weatherORD.csv", sep=""))

# weather delay ORD departure flight
ORD_departure_flight <- subset(flights_weatherdly, ORIGIN_AIRPORT == "ORD")

# joining the datasets
ORD_departure_flight$MONTH <- as.integer(ORD_departure_flight$MONTH)
ORD_departure_flight <- left_join(ORD_departure_flight,
                                    ORD_weather, by = c("MONTH", "DAY"))

barplot(table(ORD_departure_flight$MONTH),
       xlab="Month",
       ylab="Delayed flights due to weather",
       main="Weather delayed flights number in each month at airport ORD",
       ylim=c(0, 2500))
```

Weather delayed flights number in each month at airport ORD



is clear to see that the mostly delayed flights are in January and February. For those months, it is possible to see what influenced the most the delays.

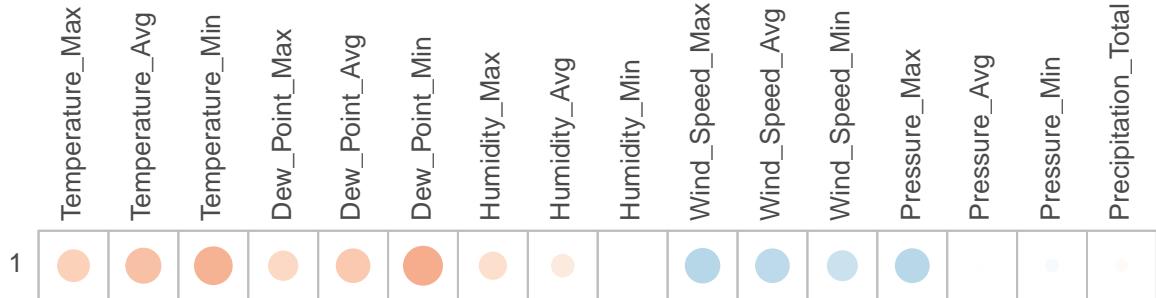
```
##Correlation between delays and weather factors
ORD_departure_Jan <- subset(ORD_departure_flight, MONTH == 1)
ORD_departure_Feb <- subset(ORD_departure_flight, MONTH == 2)

# correlation between delay and wheather
res3 <- cor(ORD_departure_Jan$DEPARTURE_DELAY, ORD_departure_Jan %>% select(33:48))
round(res3, 2)

##      Temperature_Max Temperature_Avg Temperature_Min Dew_Point_Max
## [1,]          -0.24          -0.29          -0.34          -0.2
##      Dew_Point_Avg Dew_Point_Min Humidity_Max Humidity_Avg Humidity_Min
## [1,]          -0.27          -0.36          -0.17          -0.12          -0.01
##      Wind_Speed_Max Wind_Speed_Avg Wind_Speed_Min Pressure_Max
## [1,]           0.28           0.27           0.21           0.27
##      Pressure_Avg Pressure_Min Precipitation_Total
## [1,]           0.01           0.03           -0.03

corrplot(res3,
         tl.cex = 0.8,
         tl.col = "gray29",
         cl.pos = "n",
         title = "Correlation between weather factors and weather delay")
```

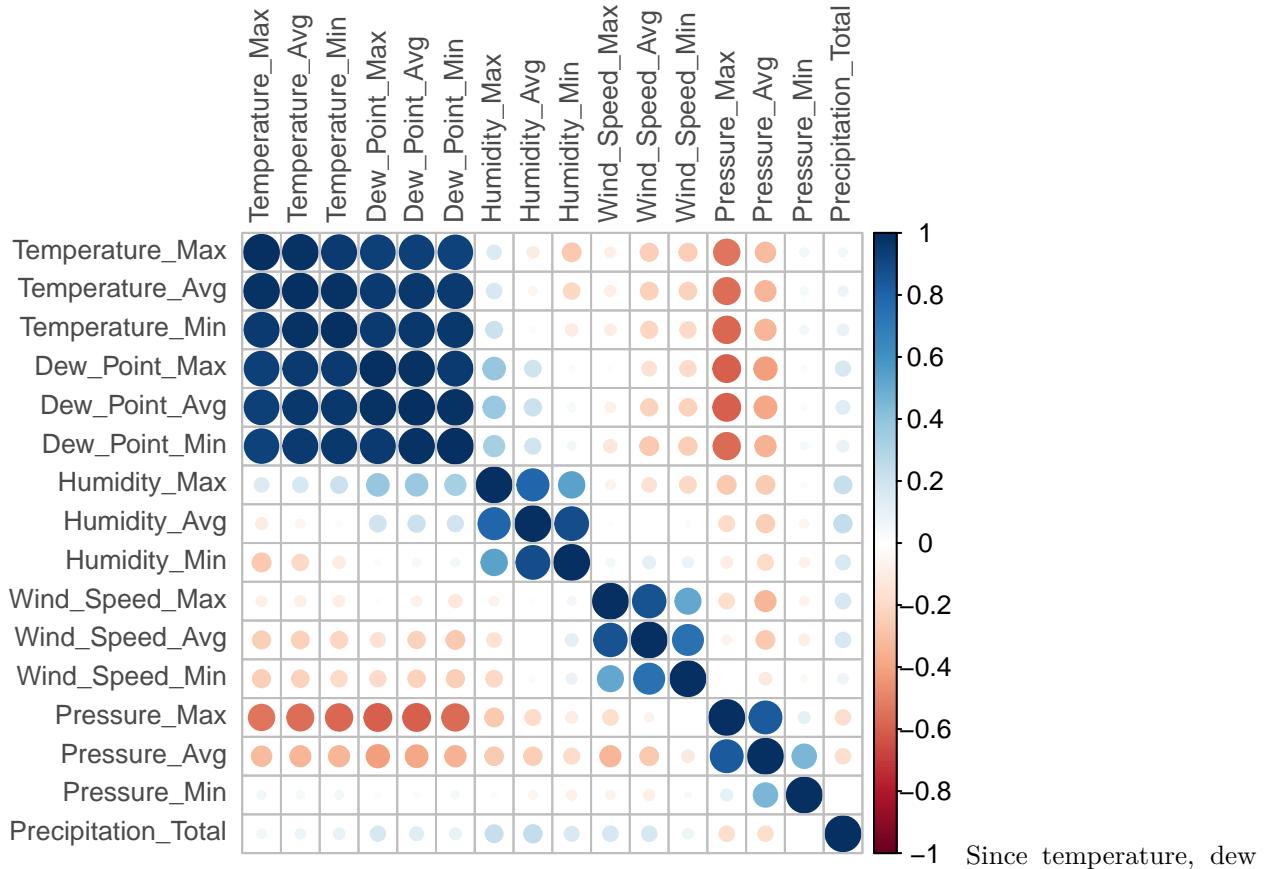
CORRELATION BETWEEN WEATHER FACTORS AND WEATHER DELAY



```
#res4 <- cor(ORD_departure_Feb$DEPARTURE_DELAY, ORD_departure_Feb %>% select(33:48))
#round(res4, 2)
```

For delayed flights in January, departure delay has a higher correlation with minimum temperature, minimum dew point, maximum wind speed, and maximum pressure. The delay flights in February has no correlation with any of these weather factors. (Still need more research in this part.)

```
# correlation matrix of weather factors
cor_weather <- ORD_weather %>% select(3:18)
res <- cor(cor_weather)
corrplot(res, tl.cex = 0.8, tl.col = "gray29")
```



Since temperature, dew point, and maximum pressure have a high correlation according to the correlation matrix, we choose only minimum dew point and maximum wind speed as independent variables of the regression model.

```
# Regression analysis
Jan_two_var <- lm(DEPARTURE_DELAY ~ Dew_Point_Min + Wind_Speed_Max,
                     data = ORD_departure_Jan)
summary(Jan_two_var)
```

```
##
## Call:
## lm(formula = DEPARTURE_DELAY ~ Dew_Point_Min + Wind_Speed_Max,
##      data = ORD_departure_Jan)
##
## Residuals:
##     Min      1Q Median      3Q     Max
## -99.28 -42.59 -14.45  23.68 646.72
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 66.0873    7.6268   8.665 <2e-16 ***
## Dew_Point_Min -1.9821    0.1751 -11.320 <2e-16 ***
## Wind_Speed_Max  0.2309    0.3785   0.610   0.542
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 64.17 on 2144 degrees of freedom
## Multiple R-squared:  0.1319, Adjusted R-squared:  0.1311
## F-statistic: 162.9 on 2 and 2144 DF,  p-value: < 2.2e-16
```

Additional Analyses with the data set

Catch-Up Rate of different airlines

The purpose of this analysis is understanding whether flights which leaves late is able to arrive on time (catch-up with the delay).

```
# extracting flights with departure delay but arrival on time
dep_dly_arrv_ontime <- subset(flights1, DEPARTURE_DELAY > 15 & ARRIVAL_DELAY <= 15)
catchup_count <- table(dep_dly_arrv_ontime$AIRLINE)

# extracting flights with noticeable departure delay
dep_dly <- subset(flights1, DEPARTURE_DELAY > 15)
delay_count <- table(dep_dly$AIRLINE)

# catch-up rate of airlines
sort((catchup_count/delay_count)*100, decreasing = T)

##
##          UA          DL          WN          AA          AS          VX          B6
## 27.290386 26.566317 22.037599 21.358594 19.126606 18.887637 18.720471
##          US          MQ          OO          NK          EV          F9          HA
## 18.389402 14.639858 14.251743 13.684943 13.526581 12.816198  7.999177
```

UA has a catch-up rate of almost 30%, which means flights departing more than 15 minutes late have 30% probability to still arrive on time.

Clustering

Clustering of airports can be performed using:

- Average distance of outcoming flights;
- Average number of outcoming flights;
- Average number of incoming flights;
- Average number of passengers.

This will likely group the airports in big/small, and delays can be compared according to the clusters.

```
passengers <- select(airports_pass, IATA_CODE, passengers_count)

flights_cluster <- flights[, .(as.integer(mean(DISTANCE, na.rm = TRUE))), by = .(ORIGIN_AIRPORT)]

outcoming_flights <- flights[ , .N, by = ORIGIN_AIRPORT]
names(outcoming_flights)[1] <- "IATA_CODE"

incoming_flights <- flights[ , .N, by = DESTINATION_AIRPORT]
names(incoming_flights)[1] <- "IATA_CODE"

names(flights_cluster)[1] <- "IATA_CODE"

flights_cluster <- merge(flights_cluster, passengers, by = "IATA_CODE")
flights_cluster <- merge(flights_cluster, incoming_flights, by = "IATA_CODE")
flights_cluster <- merge(flights_cluster, outcoming_flights, by = "IATA_CODE")

flights_cluster <- na.omit(flights_cluster)
flights_cluster$passengers_count <- as.integer(flights_cluster$passengers_count)
```

```

# converting to data frame because of row naming
flights_cluster <- data.frame(flights_cluster)
row.names(flights_cluster) <- flights_cluster$IATA_CODE
flights_cluster$IATA_CODE <- NULL

colnames(flights_cluster) <- c("Distance", "Passengers", "Incoming flights", "Outcoming flights")

```

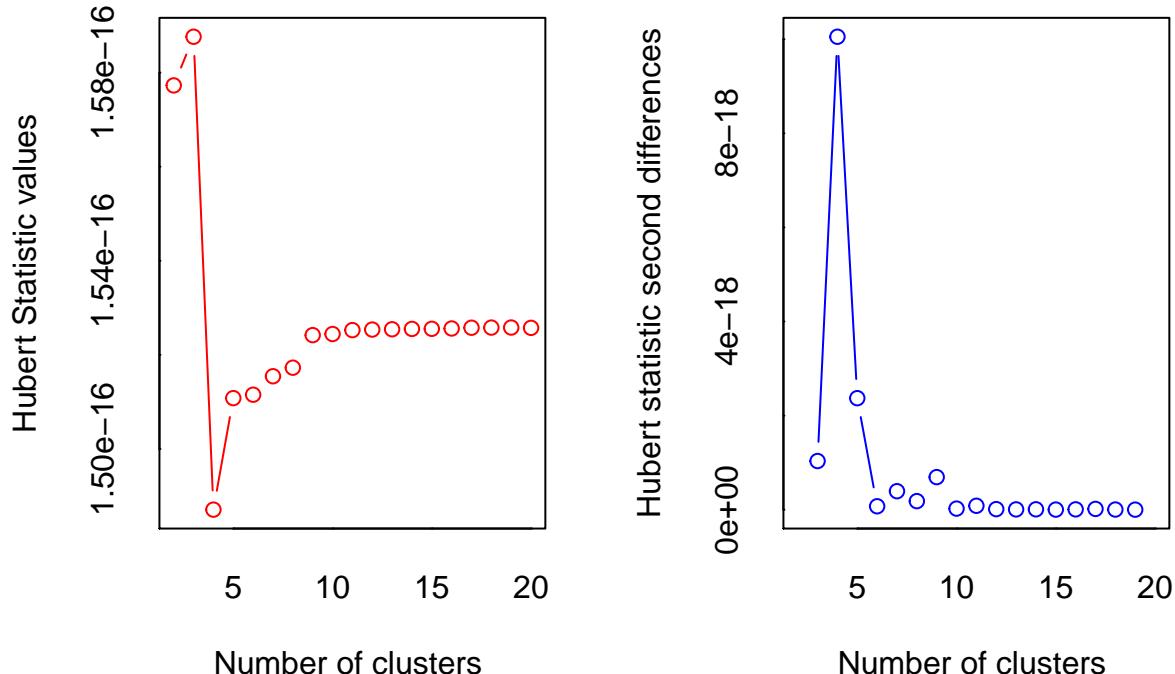
The chosen clustering algorithm is k-means, since it is a simple approach and data is suitable. To calculate the number of clusters, NbClust offers different indexes.

```

# different indexes to calculate k
ncluster <- NbClust(flights_cluster, min.nc=2, max.nc=20, method="centroid")

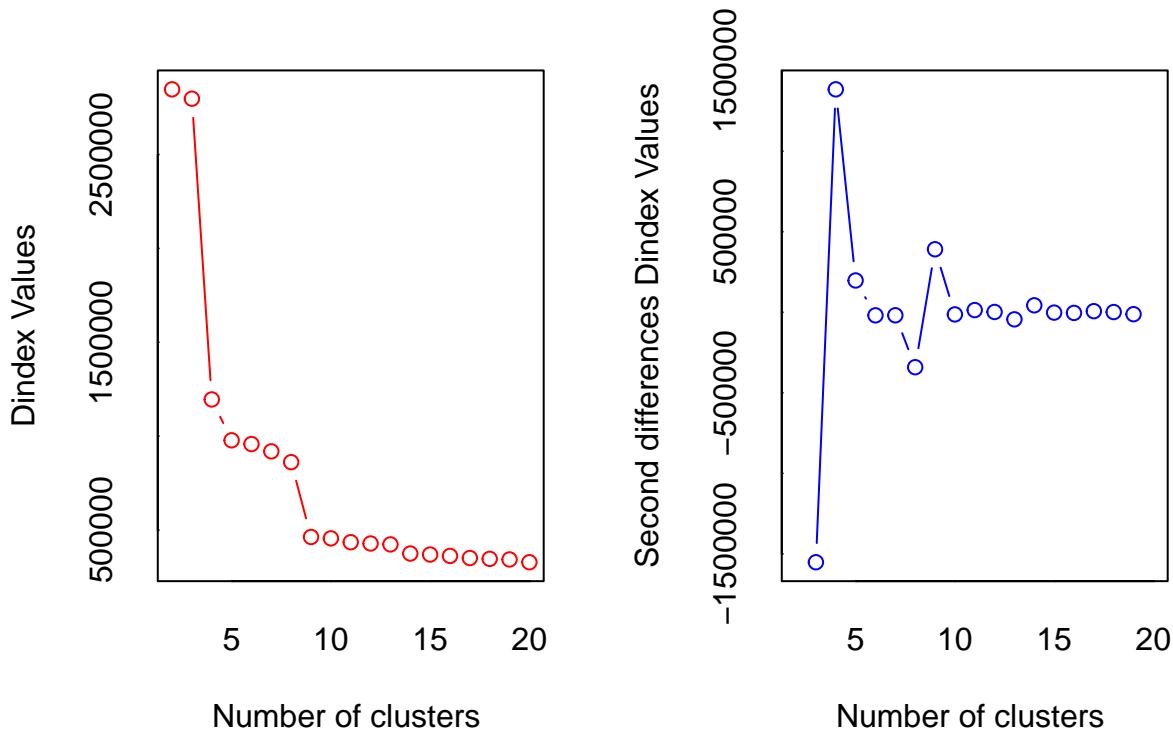
```

```
## [1] "Frey index : No clustering structure in this data set"
```



```

## *** : The Hubert index is a graphical method of determining the number of clusters.
## In the plot of Hubert index, we seek a significant knee that corresponds to a
## significant increase of the value of the measure i.e the significant peak in Hubert
## index second differences plot.
##
```



```

## *** : The D index is a graphical method of determining the number of clusters.
## In the plot of D index, we seek a significant knee (the significant peak in Dindex
## second differences plot) that corresponds to a significant increase of the value of
## the measure.
##
## *****
## * Among all indices:
## * 3 proposed 2 as the best number of clusters
## * 2 proposed 3 as the best number of clusters
## * 10 proposed 4 as the best number of clusters
## * 1 proposed 5 as the best number of clusters
## * 1 proposed 8 as the best number of clusters
## * 3 proposed 9 as the best number of clusters
## * 1 proposed 10 as the best number of clusters
## * 1 proposed 14 as the best number of clusters
## * 1 proposed 19 as the best number of clusters
##
## ***** Conclusion *****
##
## * According to the majority rule, the best number of clusters is 4
##
## *****
# 4 clusters
set.seed(1234)
clusters <- kmeans(flights_cluster, centers=4, iter.max=100, nstart=25)

clusters$size

## [1] 16 28 4 265

```

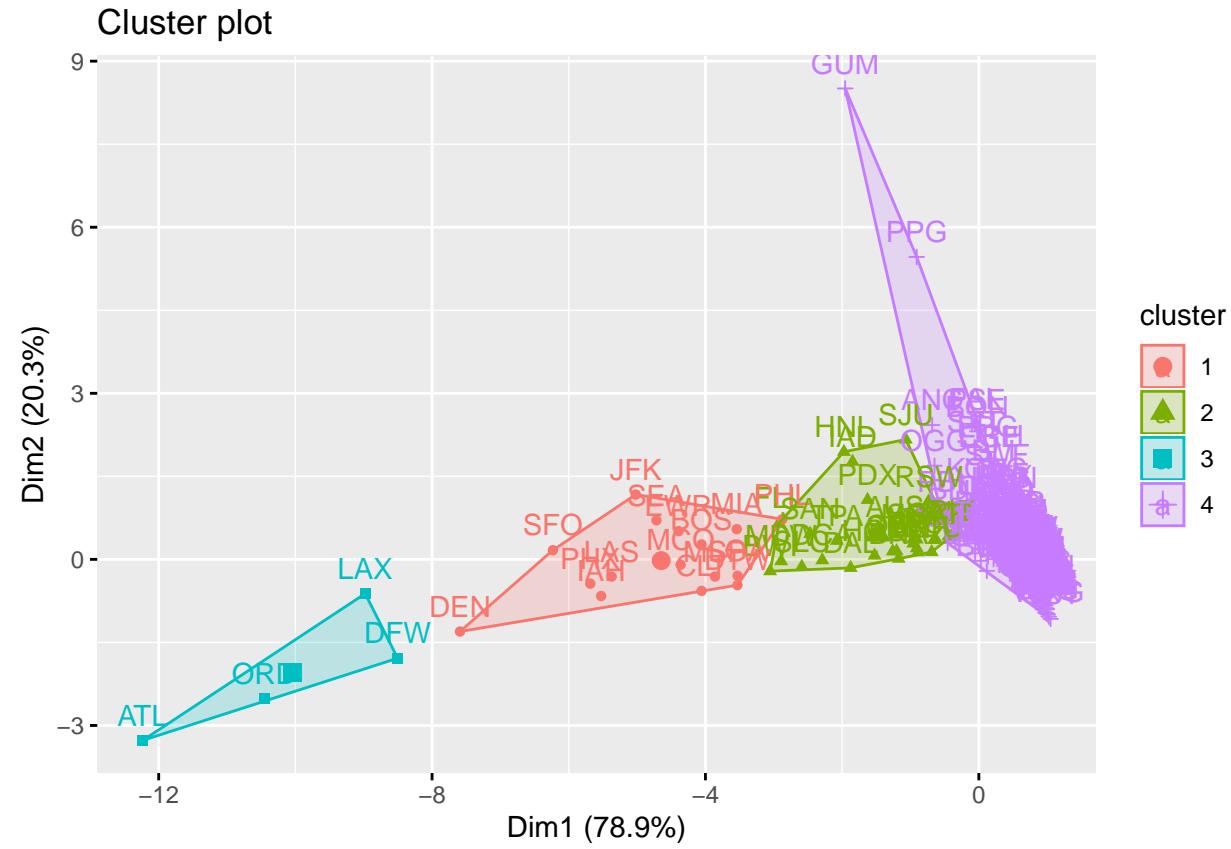
```

clusters$centers

##      Distance Passengers Incoming flights Outcoming flights
## 1 1024.0000 20134545.6          55674.375        57527.000
## 2 861.8929 6969602.5          23096.679        22674.143
## 3 883.5000 38396877.8         120806.500       131235.500
## 4 470.8717 455178.9          1825.562        1602.223

# plotting clusters
fviz_cluster(clusters, data = flights_cluster)

```



A

feasible criteria for grouping is:

- Medium/big airports with long distance flights (16);
- Medium airports (28);
- Huge airports (4);
- Small airports (265).

```

nrow(flights[ORIGIN_AIRPORT %in% rownames(flights_cluster[clusters$cluster == 1, ])])

## [1] 920432

mean(flights[ORIGIN_AIRPORT %in% rownames(flights_cluster[clusters$cluster == 1, ])]
      $DEPARTURE_DELAY, na.rm = TRUE)

## [1] 25.0114

nrow(flights[ORIGIN_AIRPORT %in% rownames(flights_cluster[clusters$cluster == 2, ])])

## [1] 634876

```

```

mean(flights[ORIGIN_AIRPORT %in% rownames(flights_cluster[clusters$cluster == 2, ])]
      $DEPARTURE_DELAY, na.rm = TRUE)

## [1] 23.86624

nrow(flights[ORIGIN_AIRPORT %in% rownames(flights_cluster[clusters$cluster == 3, ])])

## [1] 524942

mean(flights[ORIGIN_AIRPORT %in% rownames(flights_cluster[clusters$cluster == 3, ])]
      $DEPARTURE_DELAY, na.rm = TRUE)

## [1] 26.07805

nrow(flights[ORIGIN_AIRPORT %in% rownames(flights_cluster[clusters$cluster == 4, ])])

## [1] 424589

mean(flights[ORIGIN_AIRPORT %in% rownames(flights_cluster[clusters$cluster == 4, ])]
      $DEPARTURE_DELAY, na.rm = TRUE)

## [1] 26.92377

```

It can be seen that despite the negative correlation between number of passengers and flight delays, the mean of departure delay is similar for each cluster. The interesting values are related to the number of outcoming flights: just 16 airports (5%) are the origin of 36% of flights.

265 small airports only concern 424 589 flights.