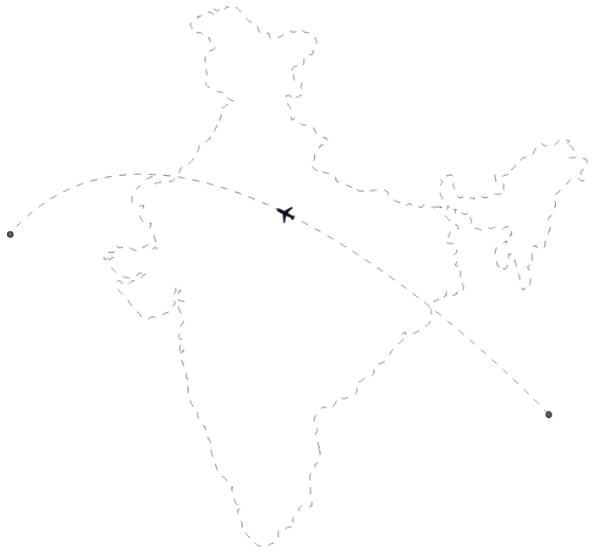
Visualizing the impact of climate change on flight experience

Trends in flight cancellations & passenger complaints for scheduled domestic airlines in civil aviation industry of India.



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ABSTRACT

During the first five months of the year 2018, the low-cost carriers in India canceled 1,824 flights, impacting around 108,000 passengers, the highest among the domestic airline carriers in India. The government data showed that around 22 million rupees (313,170 USD) were paid as pay to passengers by the airlines through May 2018. Flight cancellations leave passengers stranded and inconvenienced. The airlines are shelling out large amounts of reward for these issues. Each year, the monsoon is a dreaded period in India, especially when it comes two weeks too soon. Climate are the main cause of flight cancellations and delays ultimately impairing the passenger experience. This project aims to look into temperature and rainfall patterns for the last five years so as to analyze their correlation with flight cancellations, for scheduled domestic airline carriers in India.

This exploration can be a pilot for similar future explorations for countries around the world. This thesis is an attempt towards helping the passengers make informed air travel decisions by making them aware of the impact of climate change.

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INTRODUCTION

Aviation, probably more than any other mode of transportation, is greatly affected by the weather. Airlines are part of an interdependent aviation system that has to work towards getting passengers to their destinations safely and on time.

Many airports are built near sea level, putting them at risk of more frequent flooding as oceans rise. The frequency and intensity of air turbulence may increase in some regions due to strengthening high-altitude winds. Steadily rising temperatures with constant air pressure cause a decline in air density. ‘Lift’, the upward force created by diverting air around wings as an aircraft moves down the runway, is harder to achieve when the air is hot because hot air is thinner than cold air. Seasonal shifts and changes in weather patterns due to global warming would affect air travel at times forcing pilots to modify flight lengths, routings and in most scenarios causing flight delays and even cancellations affecting passenger’s flight experience and airline’s on-time performance. Regulation that requires airlines alone to pay compensation or provide care and assistance as a result of delays does not address the fundamental problem of ‘why delays occur’.

In India, air traffic of 131 million passengers was recorded in 2016, of which 100 million were domestic passengers. Directorate General of Civil Aviation (DGCA) of India generates monthly reports consisting of on-time performance, passenger traffic data for major scheduled domestic airline carriers. This data could be put to greater use by looking at it against the backdrop of changing weather patterns and seasonal shifts. Atmospheric Pollution and Climate Change (APCC) publishes monthly and yearly rainfall counts and temperature data for various sub-regions in India. An interesting perspective would be to have a comparative analysis of major airline carriers in terms of the cancellations, complaints to look at which airline carriers are

affected the most in order to look into the possibility of planning ahead for the future discrepancies, to understand the implications on the customer base. More importantly, this thesis aims at equipping the current and prospective passengers to make well-informed decisions in terms of which airline preference and flight experience expectations while flying during a particular month of the year.

This thesis analyzes patterns in flight cancellations and passenger complaints in Indian air travel section and contribution of the changing weather conditions to it in order to show how weather can impact service quality of airline carriers as well as the flight experience of their passengers. can potentially help passengers make well- informed choices. This paper addresses these trends in weather patterns, seasonal shift and its probable correlation with the cancellations and complaints about major scheduled domestic airline carriers from 2014 to 2018.

BACKGROUND

Impact of climate change on aviation

One perspective of looking at this topic could be ‘the impact of air travel on global warming’. Most studies so far have discussed how aviation may affect global warming, and not vice-versa. It’s a vicious circle. This thesis predominantly looks at the impact of changing weather patterns on aviation specifically on airline customers’ flight experience. Airline industries around the world are affected by recent climate changes. Rising sea levels are already threatening to swamp some major airports. In Phoenix, in the United States of America, nearly 50 flights scheduled by American Airlines for smaller regional jets were canceled in June 2017 due to summer’s spat of heat with a forecasted high of 120 degrees. The aircraft used in this particular scenario had an operating temperature of 118 degrees. This incident says a lot about how merely heat i.e. temperature, irrespective of the precipitation or hazardous winds, is capable of grounding a plane. It is important to understand the science behind this event as it ultimately resulted in bulk flight cancellations that were purely triggered by the high heat.

In an article posted by Fortune wherein pilot, Patrick Smith explained the science behind it. “Hot air is less dense. This affects the output of the engines as well as aerodynamic capabilities, increasing the required runway distance and reducing climb performance. Therefore, the number of passengers and cargo a plane can carry are often restricted when temps are very high. How much so depends on the temperature, airport elevation and the length of the available runways. And getting off the ground is only part of it: once airborne, planes have to meet specific, engine-out climb criterion, so nearby obstructions like hills and towers are another complication.”

The mechanical limitations of the planes are one of the major causes behind flight cancellations. This is a global phenomenon. Average global temperatures have

gone up nearly 1-degree Centigrade(C) i.e. 1.8 Fahrenheit (F) since 1980 (R). Rising temperatures due to climate change and global warming will make it harder for many aircraft around the world to take off in the coming years. Global average temperatures are expected to go up by another 3 degrees C (5.4 degrees F) by 2100. To further add to it, more prevalent heat waves will cause the maximum daily temperatures at the airports to rise by 4-8 degrees (7.2 to 14.4 F) by 2080.

As much as the precautionary actions by Airlines are concerned, they might have to reduce fuel capacities, cargo or even passengers to avoid cancellations or even wait and schedule flights for cooler hours to fly. Coffee and Horton (R), in the paper they published in 2015 elaborating temperature-related take-off problems for the common Boeing 737-800 at Phoenix, estimated in their predictions that this reduction would be as much as 4% on the hottest days for some aircraft. If we somehow managed to get rid of the carbon emissions soon, it could come down to 0.5%. Even this lower percentage number is very impactful for an industry that operates on a thin profit margin. This is one of the reasons why this thesis focuses on the analysis of the impact of climate change on Indian aviation.

Climate in India

India gets closest to the equator at 6°45’10″N and 93°49’36″E to its North, which is quite close. As per India Meteorological Department (IMD) (R), designates prominent climatological seasons over the year. Winter (October to February) with temperature averaging around 10–15 °C (50–59 °F) in the northwest, Summer or Pre-monsoon(April to June) with temperature averaging around 32–40 °C (90–104 °F), Monsoon(July-September), Post-Monsoon(October-November).

Several effects of global warming, including steady sea level rise, increased cyclonic activity, and changes in ambient temperature and precipitation patterns, have impacted India. Record-breaking heat waves have become a regular occurrence in India and as global temperatures continue to rise, hot-weather countries like India

are even more miserable. Such unprecedented heat waves are expected to occur more frequently in the near future and cover larger areas. This change in temperature pattern has started to affect the rainfall patterns as well. A 2°C (35.6 °F) rise in the world’s average temperatures will make India’s summer monsoon highly unpredictable. At 4°C (39.2 °F) warming, an extremely wet monsoon that currently has a chance of occurring only once in 100 years is projected to occur every 10 years by the end of the century. India is witnessing consistent warmer seasons is clear from the IMD’s analysis that pointed out that 11 out of 15 warmest years were in the last 15 years (2002-2018). The last year was also the consecutive third-warmest year after 2016 and 2017.

The India Meteorological Department (IMD) on January 16, 2018, declared that 2018 was the sixth-warmest year in the last 117 years or since 1901, Pointing towards changing weather and climate parameters, it also noted that the last monsoon rainfall was the sixth-lowest since 1901. To quote IMD, “The 2018 annual mean land surface air temperature for the country was +0.41°C above the 1981-2010 average, thus making 2018 the sixth-warmest year on record since 1901. The monsoon over India is formed due to intense solar heating in late spring as the solar maximum moves north from the equator. Future climate predictions suggest an increase in monsoon rainfall. The typical increase in total rainfall over India may be around 5-10%, although some climate models suggest more and some less (it is a bit difficult to state the exact prediction since different future climate models suggest different predictions). Predictions of the biggest impact of climate change for people in India is considered to be the variability of rainfall on shorter time scales. Intense heavy rainfall during the monsoons will lead to the floods whereas the breaks in monsoon will lead to water shortage and drought. One of the other calamities also includes tropical cyclones. The calendar month definition of monsoon is shifting rather varying with climate change. Existing calendar definition of Indian season does not account for rising temperature as well as the frequently varying length of the monsoon season.

CIVIL AVIATION, INDIA

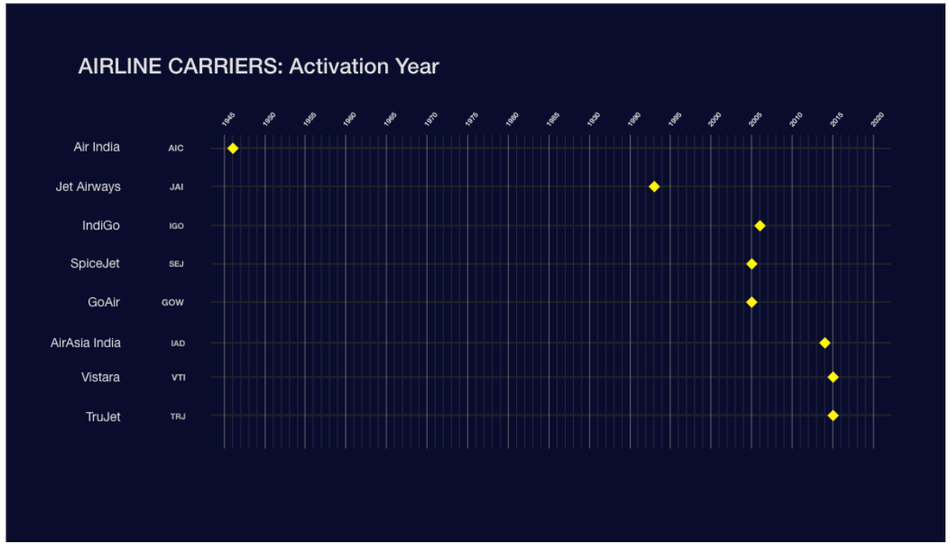
Airline Carriers

India's aviation market is expected to become the third largest in the world by 2025, according to The International Air Transport Association (IATA). India has had the world's fastest growing domestic aviation market for the past three years, according to the industry body. It forecasts that air passenger numbers too, from and within India will more than triple over the next 20 years to more than 500 million passenger journeys a year.

India remains a significantly underpenetrated market with all the Indian carriers combined having about 600 commercial planes flying between themselves. In comparison, some of the largest carriers in the US, Europe, and China would alone have more planes than this. There are eight major airlines that dominate the market, with three full-service companies including the debt-laden, state-owned Air India, and budget operators such as IndiGo and SpiceJet. With so many airlines, there is rising competition, and as companies add more flights, it has become increasingly difficult to be profitable. Typically, in the aviation industry, one would see higher fares to cover the increased costs, however, that's not what is happening with some of the airlines that have incurred losses. They are adopting various initiatives to reduce the fuel burn on the planes by reducing. Analysts say the industry is rapidly moving towards a situation where there is likely to be a reduction in the number of players. "While it is easy to find Indian passengers who want to fly, it's very difficult for airlines to make money in this market," says Alexandre de Juniac, the director general and chief executive at IATA. "India's social and economic development needs airlines to be able to profitably accommodate growing demand. We must address infrastructure constraints that limit growth and government policies that deviate from global standards and drive up the cost of connectivity." There is the enormous potential for the industry, in a country where only a single-digit percentage of the 1.3 billion-strong population flies, and where more people are taking to the skies amid rising incomes and the sector's expansion.

India is the third-largest civil aviation market in the world having the potential of becoming a second-largest aviation market by 2020. It recorded air traffic of 131 million passengers in 2016, of which 100 million were domestic passengers. The largest airline by international passenger traffic was Jet Airways which transported over 10 million passengers in and out of India in 2016, followed by Air India. IndiGo, Jet Airways, Air India, SpiceJet, GoAir and Vistara, AirAsia India are the major carriers in order of their market share. These airlines connect more than 80 cities across India and also operate overseas routes after the liberalization of Indian aviation. However, a large section of the country's air transport potential remains untapped, even though the Mumbai–Delhi air corridor is ranked 3rd among the world's busiest routes.

This thesis exploration considers 8 major airlines operational during 2014-2018 carriers Air India, Jet Airways, SpiceJet, GoAir, Indigo, AirAsia, Vistara and TruJet. These are some of the oldest and longest running airline carriers operating in the Indian civil aviation sector.



Impact of weather on flight operations

With the economy closely coupled with its natural resources and climate-sensitive sectors such as agriculture, water, and forestry, India may face a major threat because of the projected changes in climate in the years to come. When it comes to safety, identifying the circumstances and causes of an aircraft accident is of great significance in helping avoid similar accidents in the future. Besides attribution of various aircraft accidents to avionic causes, bad weather is another prime cause for accidents of many aircraft and helicopters in India. During 2000–2012, two major aircraft accidents occurred in India. On July 27, 2000, the 'Alliance Air flight CD-7412' crashed at Patna airport, killing 60 passengers and on May 22, 2010, 'Air India Express Flight 812' crashed at Mangalore airport, killing 158 passengers. There also have been a number of other aircraft accidents from the non-scheduled category in India. Various studies undertaken outside India show how the weather is regarded as one of the main causes of aircraft accidents and incidents 4–6. Among different weather hazards, thunderstorms, microburst, mountain wave turbulence, clear air turbulence (CAT), wind shear, poor visibility, and fog are the major causes of aircraft incidents.

While conducting this analysis I had to keep in mind that weather is not the only contributor to the flight cancellations. Directorate General of Civil Aviation (DGCA) lists Technical, Operational, Commercial, Miscellaneous among other reasons behind these cancellations. Although, the incidents listed above show the intensity of the impact of weather on flight operations.

Directorate General of Civil Aviation (DGCA)

Directorate General of Civil Aviation (DGCA) is the regulatory body governing the safety aspects of civil aviation in India. Some of the major functions of DGCA include Registration of the civil aircrafts, examination of aircraft's airworthiness, licensing aviation professionals such as pilots, aircraft maintenance engineers, air traffic controllers and flight engineerings conducting regular aircraft checkups, Conducting investigation into incidents and serious incidents involving aircraft up to 2250 kg AUW

and taking accident prevention measures including formulation of implementation of Safety Aviation Management Programmes, Granting approval to aircraft maintenance, repair, design and manufacturing organizations and their continued oversight etc.

DGCA publishes monthly reports covering various statistics related to operations of the civil aviation sector. These reports are one of the primary data sources this exploration is based upon. I contacted some of the key officials at DGCA who directed me to some of the related information.

USER STUDY

The primary audience of this exploratory data visualization would be the domestic passengers. The data visualization would assist the passengers to be more aware of the cancellations recorded during a particular climatic season experienced in India in terms of the weather parameters Temperature and Rainfall. This would probably enable passengers to make better travel decisions in consideration of a particular season during a certain month. The idea is to try to avoid the inconvenience caused due to flight cancellations. Availability of data has undeniably played a role for me in deciding to limit this exploration and analysis to only eight major airline carriers. The visualization also highlights upcoming Indian holidays for 2019 for further assistance for traveling during a certain holiday or a festival celebration and which airlines to consider for the same.

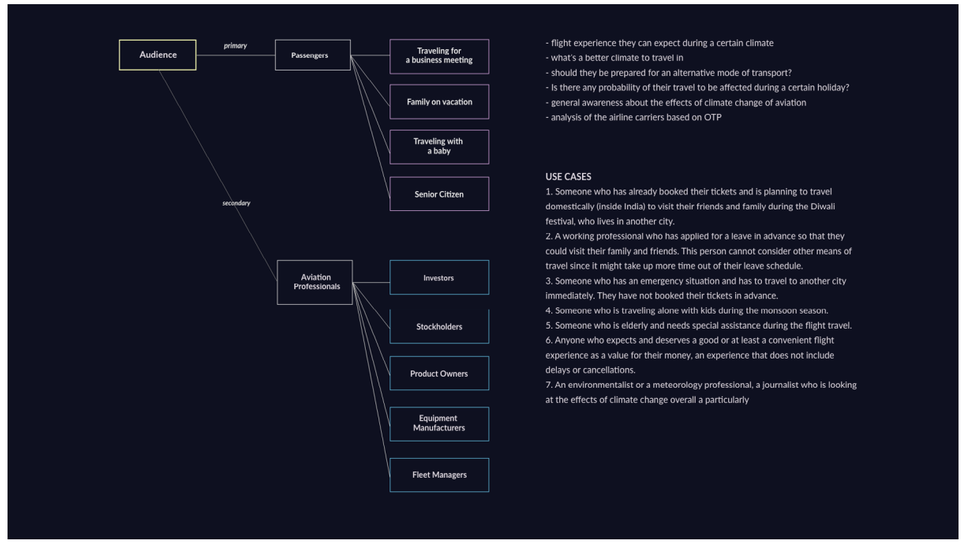
The secondary audience would be aviation professional or anyone who is interested in the impact of climate change on various businesses and industries.

I have considered a few use case scenarios for this exploration as it surrounds around the flight experience of the audience. Passengers of primary consideration and most of these use case scenarios are about the passengers and a few are about the aviation administration. They are as follows:

1. Someone who has already booked their tickets and is planning to travel domestically in India to visit their friends and family during a certain festival.
2. A working professional who has applied for a vacation break well in advance, so that they could visit their family and friends. This person cannot consider other means of travel since it might take up more time out of their vacation break schedule.
3. Someone who has an emergency situation and has to travel to another city immediately and they have not booked their flight tickets yet.
4. Someone who is traveling alone with kids during the monsoon season.

5. Someone who is elderly and needs special assistance during the travel.
6. Anyone who expects and deserves a good or at least a convenient flight experience as a value for their money, an experience that does not include delays or cancellations.
7. An environmentalist or a meteorology professional, a journalist who is researching the impact of climate change.
8. Aviation professionals, business professionals who care about the end-user experience and want to improve the on-time performance for their airline carriers. This exploration can easily lean towards the direction of comparative performance analysis of aircraft or can even be extended to a fleet or to an entire airline carrier service.

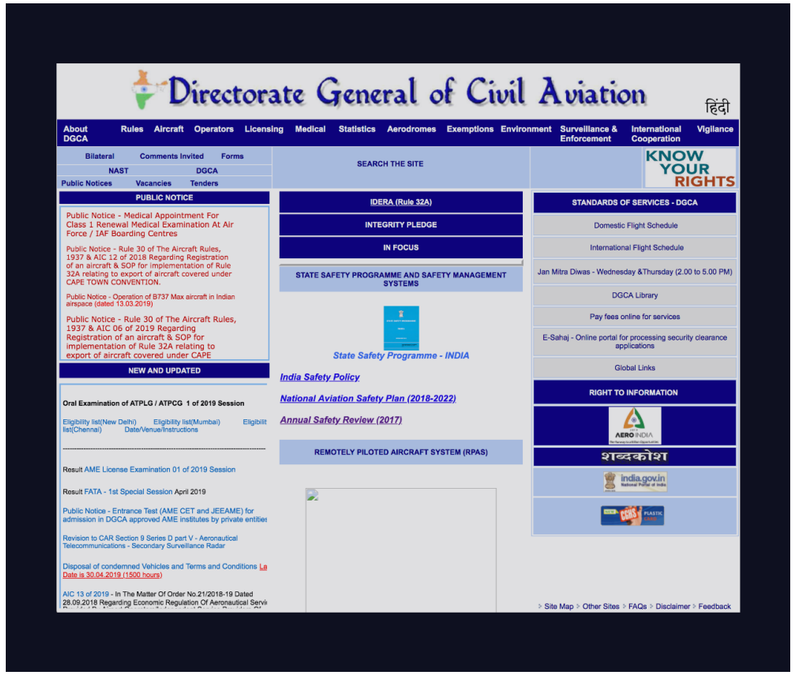
These are just a few scenarios that come to my mind at the moment. It is possible that some upcoming real-life scenario could be completely new, or almost similar or even a combination of one or more scenarios listed here.



TREATMENT

Data acquisition and integration

The primary data source of the information on airline carries is DGCA, specifically the monthly domestic air traffic, air transport reports and yearly handbooks published by DGCA. These reports mainly information about the major operational airline carries, their performance, number of passengers, monthly and yearly passenger growth, carrier capacity in terms of passengers (PAX) and cargo carried, cancellation statistics, complaints, the broader reasons contributing towards such cancellations and complaints, on-time performance, compliance of the airline carriers with the route dispersal guidelines, market share, etc. statistics on the major operational scheduled domestic carriers. I filtered the data related to eight operational major carriers from 2014 to 2018 since I wanted to look into the trends for these five years. This data is available in either excel sheets format or in PDF format.



I contacted some of the key officials at DGCA regarding some additional datasets. Although it was not of much help, they did point me to the relevant sections under DGCA where some required data were available. The data available in the excel format could not be readily copied to be collected in alternate files. I used open source table extraction tools such as 'Tabula' to detect and extract the data in tabular format.
I filtered the data based on cancellation and complaints, passengers traffic, airline carriers in order to boil it down to the data necessary for this exploration.

Instead of relying entirely on only one data source I decided to confirm this data with the tourism sector of Open Government Data (OGD) Platform India. OGD has a great collection of data from all the different sectors under the Indian government. The portal is intended to be used by Government of India departments and their organizations to publish datasets, documents, services, tools and applications collected by them for public use. OGD platform intends to increase transparency in the functioning of Government and also open avenues for many more innovative uses of Government data to give a different perspective.

Thesis research also involved looking into the census data at http://www.censusindia.gov.in and data about the airports in India at https://www.flightradar24.com/data/airports/india.

The next step in data acquisition was to acquire weather data. The temperature and rainfall data are acquired from the India Meteorological Department - Ministry of Earth Sciences. The Indian Institute of Tropical Meteorology and it is Environmental Information System Resource Partner - Atmospheric Pollution & Climate Change (APCC), a few other publications related to climate change at https://www.tropmet.res.in/~lip/Publication/RR-pdf/RR-138.pdf. Acquired values were cross-confirmed with World Weather Information Service provided by the World Meteorological Organization. They provide the monthly mean minimum and mean maximum averages for temperature and rainfall.

The data on upcoming holidays were obtained from Public Holidays in India. OfficeHolidays publishes a yearly schedule for holidays for various countries, by contents, national holidays, countdowns for the holidays, upcoming holidays, etc. There is another resource - Bankbazar that takes a step further to enlist the central holidays along with the information on what holiday is prominently celebrated in which region of India.

The initial stage of the treatment was about collecting all the required data in a processable format. As mentioned above, the required datasets were obtained from multiple publicly available sources. Next step was to filter and integrate it into a single file format. The sources mainly included Open Government Data Platform of India, Directorate General of Civil Aviation and Indian Institute of Tropical Meteorology. After the integration, the final CSV consists of the following columns:

Column Name	Description
year	year
month	the month of the year
XYZ_can	XYZ: ICAO code of the carrier: cancellation rate (%)
XYZ_com	XYZ: ICAO code of the carrier: complaints rate (%)
XYZ_pax	XYZ: ICAO code of the carrier: number of passengers (%)
XYZ_flights	XYZ: ICAO code of the carrier: number of flights (%)
XYZ_aff	XYZ: ICAO code of the carrier:
avg_temp	Average temperature (°C)
rainfall_actual	Actual Average rainfall (mm)
overall_can_rate	Overall cancellation rate(%)- an average of all operating airlines of the month (based on number of flights)
can_r1 to can_r5	Noted reasons behind the cancellations
com	An average number of complaints
com_rate	Overall complaints rate(%) (calculated per 10000 passengers)
com_r1 to com_r9	Noted reasons behind the complaints

The weather data on Tropmet website were displayed in tabular fashion with some sort of lock on the copying feature with no option available to download it.
The image below shows an example of a data set available on DGCA:

MONTHLY TRAFFIC AND OPERATING STATISTICS OF SPICEJET AIRWAYS ON SCHEDULED DOMESTIC SERVICES DURING 2018 (Provisional)

MONTH	AIRCRAFT FLOWN			PASSENGERS CARRIED (IN NUMBER)	PASSENGER KMS PERFORMED (IN THOUSAND)	AVAILABLE SEAT KILOMETRE (IN THOUSAND)	PAX.LOAD FACTOR# (IN %)	CARGO CARRIED			TONNE KILOMETRE PERFORMED				AVAILABLE TONNE KILOMETRE (IN THOUSAND)	WEIGHT LOAD FACTOR## (IN %)
	DEPARTURES (IN NUMBER)	HOURS (IN NUMBER)	KILOMETRE (IN THOUSAND)					FREIGHT (IN TONNE)	MAIL (IN TONNE)	TOTAL (IN TONNE)	PASSENGER (IN THOUSAND)	FREIGHT (IN THOUSAND)	MAIL (IN THOUSAND)	TOTAL (IN THOUSAND)		
JAN	11,145	14,914	8,614	1,447,537	1,313,294	1,381,733	95.0	5,539.0	0.0	5,539.0	98,497.0	5,685.0	0.0	104,182.0	120,033.0	86.8
FEB	10,230	13,732	7,847	1,331,645	1,198,160	1,244,492	96.3	5,206.9	0.0	5,206.9	89,867.2	5,419.3	0.0	95,286.5	108,397.3	87.9
MAR	11,517	15,241	8,805	1,474,206	1,322,852	1,392,144	95.0	5,964.6	0.0	5,964.6	99,213.9	6,151.0	0.0	105,364.9	121,358.9	86.8
APR	11,026	14,732	8,503	1,426,801	1,284,337	1,344,688	95.5	5,567.9	0.0	5,567.9	96,325.3	5,756.2	0.0	102,081.5	117,308.7	87.0
MAY	11,488	15,429	8,834	1,459,005	1,319,543	1,391,958	94.8	6,146.0	0.0	6,146.0	98,965.7	6,397.6	0.0	105,363.3	121,709.7	86.6
JUNE	11,015	14,724	8,381	1,370,265	1,226,187	1,314,145	93.3	7,159.1	0.0	7,159.1	91,964.0	7,332.7	0.0	99,296.7	114,931.3	86.4
JULY	11,401	15,101	8,545	1,427,257	1,248,731	1,331,839	93.8	7,600.8	0.0	7,600.8	93,654.8	7,985.0	0.0	101,639.8	116,534.2	87.2
AUG	11,328	14,816	8,431	1,404,424	1,229,719	1,313,965	93.6	7,459.6	0.0	7,459.6	92,228.9	7,882.8	0.0	100,111.6	115,152.9	86.9
SEP	10,975	14,500	8,357	1,362,564	1,214,946	1,303,993	93.2	8,039.3	0.0	8,039.3	91,120.9	8,858.4	0.0	99,979.3	114,883.3	87.0
OCT	11,518	18,367	8,762	1,382,010	1,239,910	1,365,552	90.8	8,345.6	0.0	8,345.6	92,993.3	7,733.6	0.0	100,726.9	119,428.1	84.3
NOV	11,794	16,007	9,270	1,454,822	1,330,631	1,461,380	91.1	7,193.0	0.0	7,193.0	99,797.3	7,158.1	0.0	106,955.4	127,426.7	83.9
DEC	12,473	17,115	9,906	1,563,700	1,448,751	1,562,334	92.7	8,419.6	0.0	8,419.6	108,654.9	8,130.9	0.0	116,785.9	136,026.0	85.9
TOTAL	135,910	184,678	104,255	17,104,236	15,377,060	16,408,222	93.7	82,641.3	0.0	82,641.3	1,153,283.3	84,490.6	0.0	1,237,773.8	1,433,190.0	86.4

SOURCE:-ICAO ATR FORM A FURNISHED BY SPICEJET AIRWAYS
NOTE:- # PAX LOAD FACTOR = (PAX KM PERFORMED/AVAILABLE SEAT KMS)*100
WEIGHT LOAD FACTOR = (TONNE KMS PERFORMED/ AVAILABLE TONNE KMS)*100

I could extract some data by downloading webpages as PDF documents and using Tabula like open source software. Tabula auto-detects the tables inside PDF files or it allows the users to select a particular area to exact the tabular information from. This made the task of extraction easier. Some of the weather data- missing entries for intermediate months needed to be found. The available data also needed to be double checked. The averages to find the yearly data still needed to be done. I decided to cross-check the acquired data with global weather information websites such as Climate World, which provides weather averages based on locations, countries, regions for monthly, daily and yearly weather data. This data was acquired by interacting with the website manually. Some data acquired from global climate websites required unit conversions for temperature data from Degree Fahrenheit to

Degree Celsius. In India, temperatures are usually measured, used and represented in Degree Celsius. Data on upcoming holidays that were obtained from BankBazaar, was by downloading the webpage as PDF and extracting tables using Tabula.

Extracted tabular data consisted of a lot of extraneous flight information such as departures, hours covered, kilometers, passengers KMs performed, available seat kilometer, PAX Load Factor, freight carried, mail carried, cargo carried by airline for that month, available Tonne Kilometers, Weight Load Factor, etc. whereas I needed information only on passenger traffic, cancellations, reasons contributing factors behind these cancellations, cancellation rate and passenger complaints rate, airline-wise information and averages for the domestic civil aviation industry, etc. I filtered out these required columns from the integrated large datasets I initially stored on Google Sheets. Data were arranged in year-month pairing and aggregated to add new columns and rows with averages as would it be required for the graphical representations I had planned for. Once ready, I downloaded the dataset as one CSV file and converted it to JSON with the help of an open source web tool: ConvertCSV.

I decided to conduct an initial analysis of the data based on the initial hypothesis, according to which, weather impacts flight cancellations and there was some correlation between weather patterns and flight cancellations. The assumption made here is that passenger complaints are one of the aftermaths of bad flight experience. This does not mean those flight cancellations is the only cause behind passenger complaints. For an overall analysis of the civil aviation sector, the cancellation rate is calculated based on all the operating airlines during a particular month. The following image shows the graph of cancellation rate plotted for June 2014- December 2018:

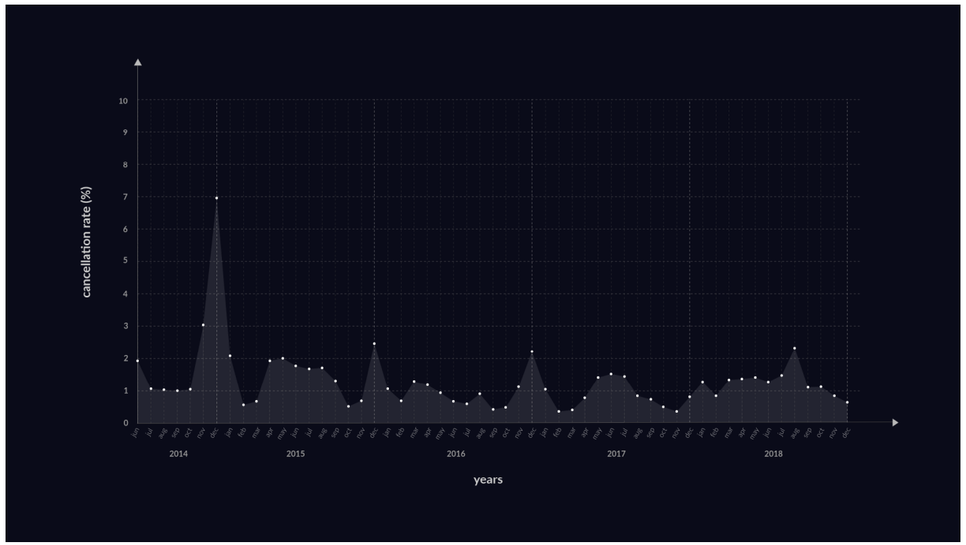


Image: cancellation rate (%) based on the number of flights

Multiple factors contribute to the overall cancellations. Some examples of the commercial factors are- not having enough booking to cover the minimum costs for the flights, high-level business decisions, etc. Operational reasons include mechanical issues, the plane might be needing repairing e.g. hydraulic leakage, faulty engine, basically, everything that contributes to the operational readiness of the aircraft. Technical issues are mainly related to digital systems, applications e.g. there might be a glitch in the computer, weak of signal strength for wireless communication, unavailability of the flight paths and maps provided to the pilots on the PFD and MFD displays installed inside the flight deck, etc. An example of the miscellaneous reason would be missing flight crew, pilot unwell or unfit to fly, lack of supplies, etc. All sort of bad weather conditions contributes to the weather category. The distribution graph below shows the contribution of these categories towards flight cancellations from Jun 2014 to Dec 2018.

After observing the plot of the contribution of weather and the plot of cancellation

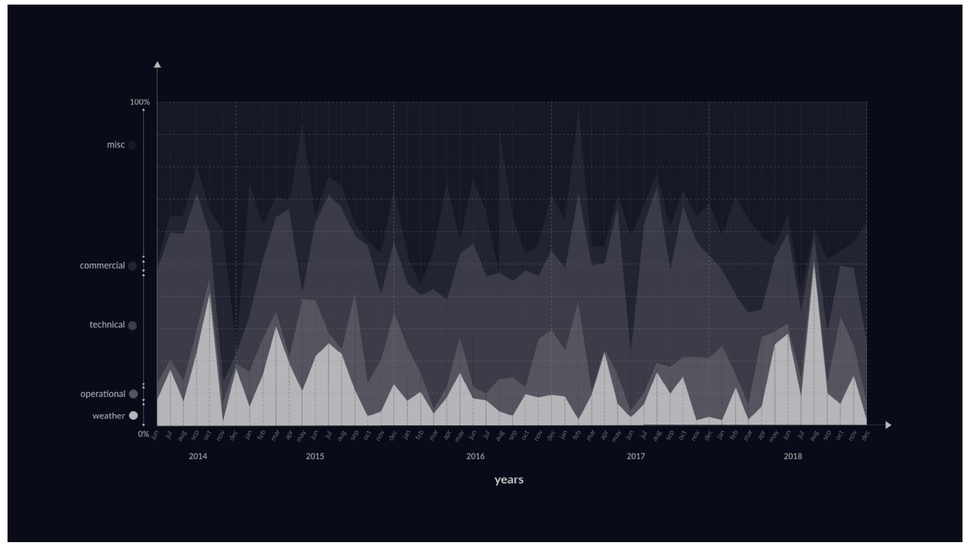


Image: contribution of diffrent factors towards flight cancellations

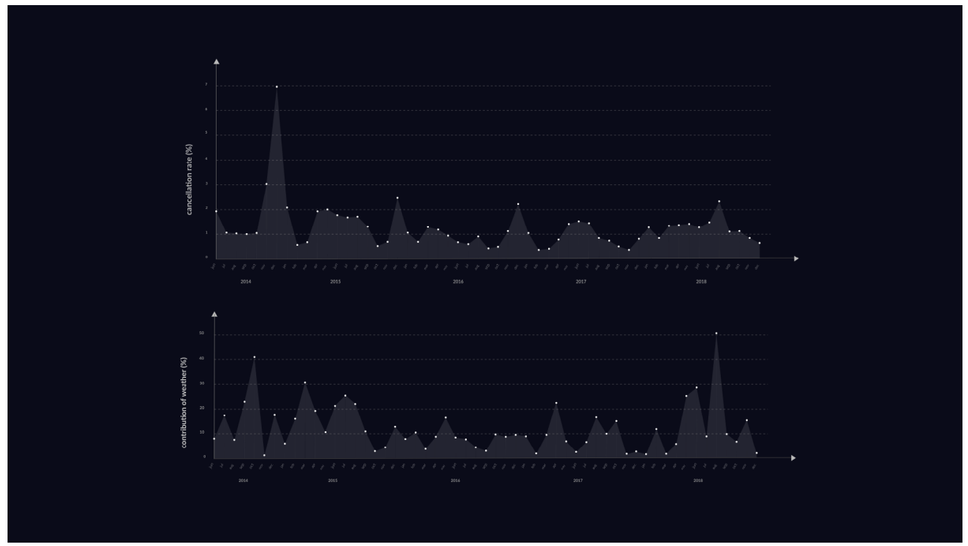


Image: contribution of weather and flight cancellations rate

rate, there seemed to be a correlation between the two entities. I decided to look into the details of this scenario in terms of parameters contributing to weather, temperature, and rainfall, especially considering the fact that India experiences prominent climatic seasons. Following graph shows the trends in average temperatures. The temperature averages are based on the monthly average temperatures recorded at 370 locations across India.

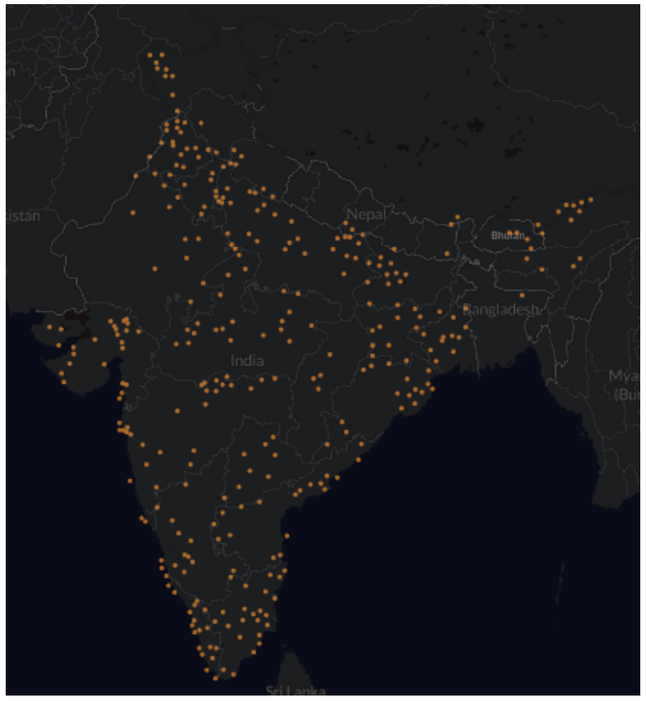


Image: average temperatures taken at these 370 locations across India

In the yearly graph of the average temperature below, we see that the average temperature in 2014 was 29.72°C whereas in 2018 it was 33.29°C. The average temperature has increased by around 3.57°C over the last 5 years. Whereas, the highest average temperature noted in 2014 was 34.15°C and in 2018 it was 37.40°C. It has increased by around 3.25°C. The past four years, from 2015 to 2018, were the warmest ever recorded.

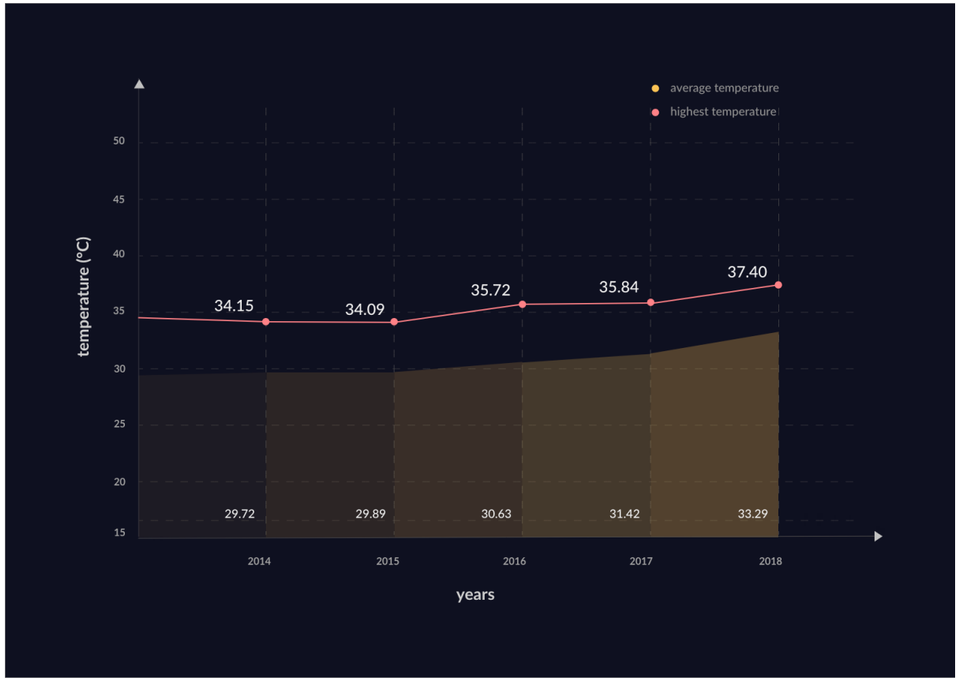


Image: average temperature in India (2014-2018)

In the yearly graph of the average temperatures, we see that the average temperature in 2014 was 29.72 °C whereas in 2018 it was 33.29 °C. The average temperature has increased by around 3.57 °C over the last 5 years. Whereas, the highest average temperature noted in 2014 was 34.15°C and in 2018 it was 37.40°C. It has increased by around 3.25°C. The past four years, from 2015 to 2018, were the warmest ever recorded.

One of the impacts of warmer surface temperatures and more ocean heat will be a greater occurrence of extreme weather events such as tropical cyclones, heat waves, floods, and droughts. In 2018, there were 70 tropical cyclones all over the world, while the long term average is 53. Only recently, in May 2019, India was hit by one of its biggest cyclones - Cyclone Fani which barrelled into Bangladesh and hit the eastern Indian state Odisha. Along with the destruction caused, it also affected domestic

flights. This is just one of the examples of myriad ways in which rising temperatures can possibly contribute to the flight cancellations in the future.

Rainfall experienced across is India during the pre-monsoon, monsoon, and post-monsoon seasons is as diverse as the temperature is. The average monthly and yearly rainfall averages were calculated based on the average rainfall counts recorded at 47 different regions across India.

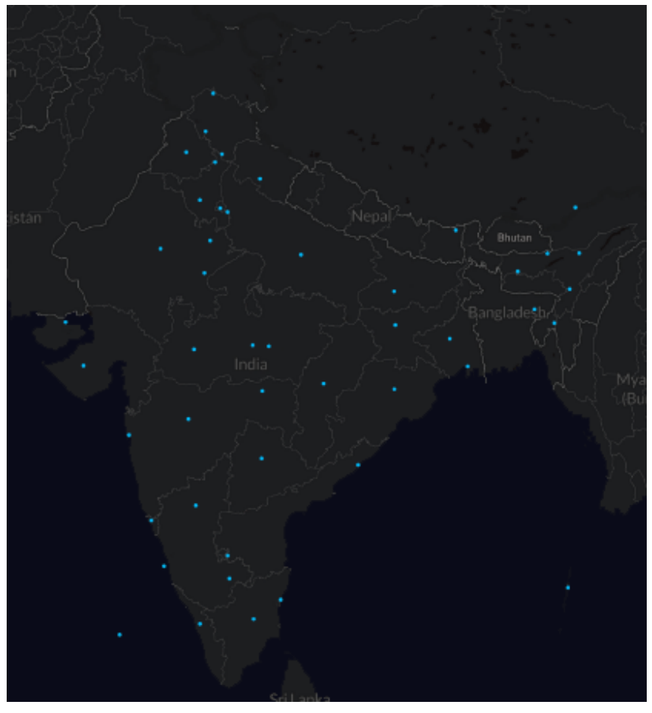


Image: average rainfall taken at these 47 locations across India

The graph below shows that although the highest noted average has been inconsistent, the average rainfall has increased gradually from 103.22 mm in 2014 to 121.55 mm in 2018.

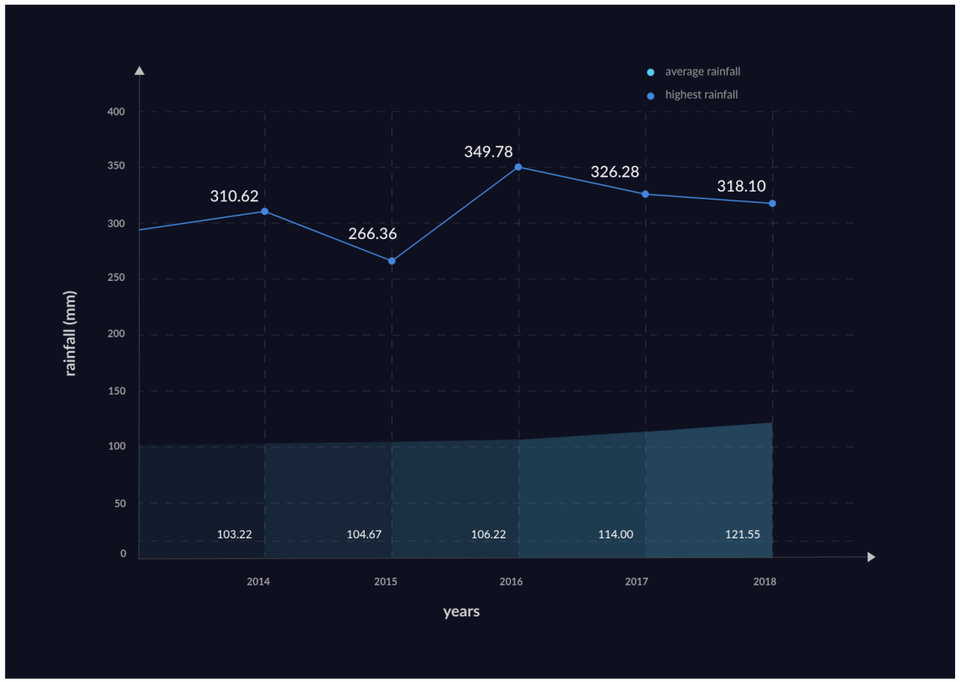


Image: average rainfall in India (2014-2018)

Design concepts and Prototype

Design concepts were initially sketched on paper and finalized interactive visualizations were prototyped in Adobe XD.

1. Linear mapping of the flight cancellations and passenger complaints against the backdrop of temperature and rainfall

For the linear mapping, I designed heat maps for the representation of temperatures and rainfall values ranging from minimum to the maximum values recorded during the period in consideration i.e. Jun 2014 to Dec 2018. The data for the first 5 months of 2014 was not available. These heat maps not only highlight the months with the high-

heat and high-rain but also assist with an instant understanding of the summer and the monsoon patches. Specifically, the linear implementation helps with understanding the relationship between the two seasons in terms of the timeline- overlapped time between the two seasons, a stretch of one season in a particular year compared to the stretch of the other, etc. additional information can be easily gathered using this visual.

The data-driven visuals and interactivity were achieved by coding in javascript, HTML, CSS and utilizing the d3js library. For the heatmap, a block for one year was implemented as a group of rectangles with the color ranging within a pre-set range. This block itself being a group was repeated for all the consecutive years. The height of rectangles also acts as a range for the cancellation rate (%) and passenger complaints rate (%), ranging from 0% to 100%. This makes it further easy to study the correlation between flight experience and climate in a glance. A small amount

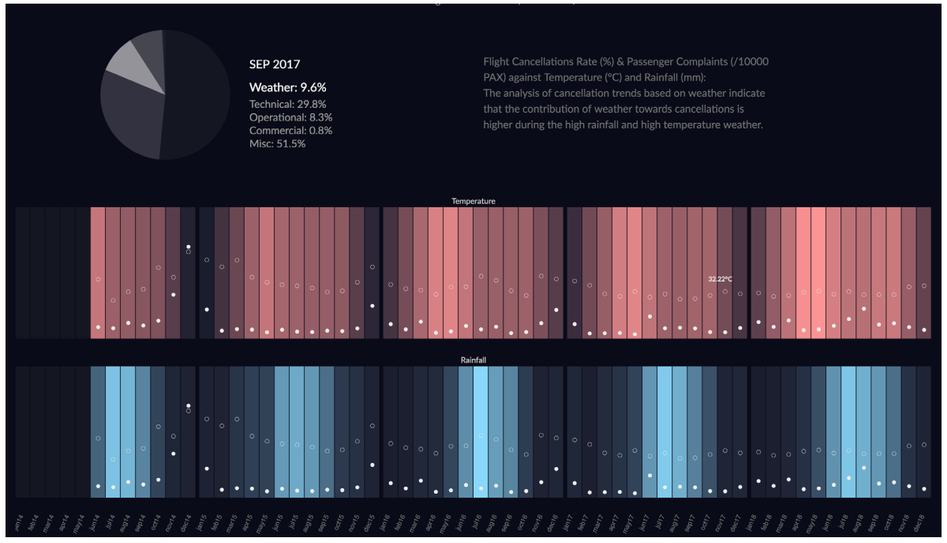


Image: temperature, rainfall and cancellation trends

of interactivity is added to view a pie chart representing the contribution of each category of the reasons along with the contribution of weather towards cancellations for a particular month.

2. Comparison of eight major airline carriers on the basis of flight cancellations and passenger complaints: A scatter plot shows this comparison wherein the size of the circles represents the cancellation or complaints rate.

3. A circular mapping representing season based impact and flight cancellations: Spokes are labeled with ICAO code of the respective airline carrier. Each airline has one spoke dedicated to each month. Highlighted spokes represent the selected airline carrier. A progression of concentric circles towards the outermost rim represents an increment of 5 in the percentage value represented by the length of the spokes. The circular space is divided into 12 sectors, each representing a month. On selection of any airline carrier from the sidebar, the cancellation rate values are plotted on the circular skeleton base. The circular structure helps to detect the outliers in data samples. A toggle switch located at the center of the circular based allows users to switch between flight cancellation rate and passenger complaints rate. An additional option to plot values for ‘all carriers’ is provided as a checkbox UI element.

One of the interesting functions of this visual is users can compare airlines and look at the upcoming holiday schedule, check the history of a particular airline carrier in terms of its cancellations rate for last five years, etc. well before applying for leave at and confirming their travel plans. A minor visual detail is the order of airline carriers on the sidebar is based on the order of the year of their activation. AIC (1946), JAI (1993), SEJ (2005), GOW (2005), IGO (2006), IAD(2014), VTI (2015), TRJ (2015).

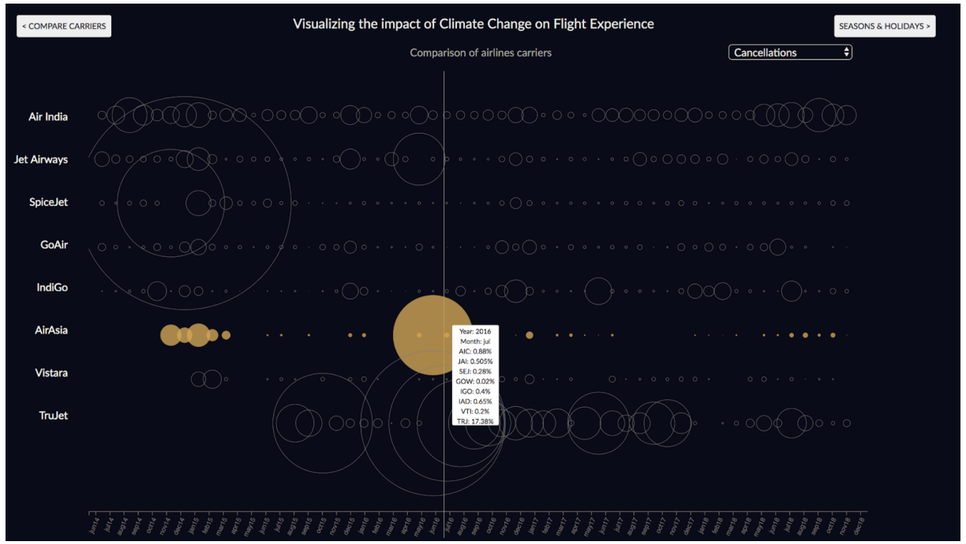


Image: comparison of airline carriers

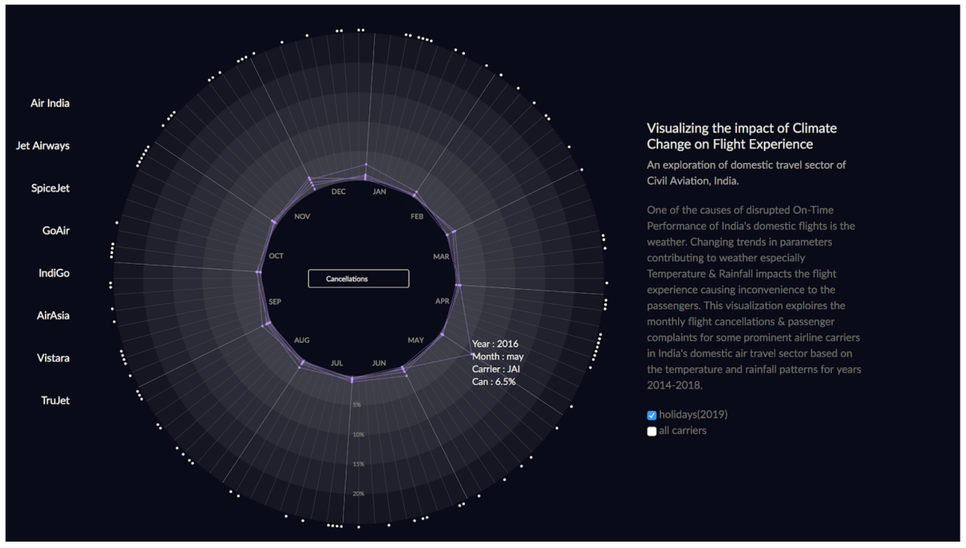


Image: circular mapping- outliers and upcoming holidays

CHALLENGES

One of the major challenges during the data collection was that the climate across India is diverse. India experiences a variety of climates ranging from tropical in the south to temperate and alpine in the Himalayan north. The elevated areas receive sustained snowfall during winters. The Himalayas and the Thar Desert strongly influence the climate of the country. The Himalayas work as a barrier to the frigid katabatic winds, which blow down from Central Asia. The Tropic of Cancer passes through the middle of the country and this makes its climate more tropical. India is a big tropical country and is famous for its diverse climatic features.

The climates of India are mainly divided into four different groups. The classification of these groups is based on the Koppen climate classification system. The Western Ghats, the Malabar Coast, southern Assam, Lakshadweep and Andaman, and the Nicobar Islands have the tropical monsoon climate. It experiences moderate to high temperature with seasonal but heavy rainfall. The months from May to November experience the most rainfall and the rain received during this period is sufficient for vegetation throughout the year. Karnataka, central Maharashtra, some parts of Tamil Nadu and Andhra Pradesh experience the tropical semi-arid (steppe) climate. Rainfall is very unreliable in this type of climate and the hot and dry summers are experienced from March to May. The areas of the tropical desert that runs from the regions of Punjab and Haryana to Kathiawar witness the sub-tropical semi-arid (steppe) climate. The maximum temperature in summers goes up to 40°C and the rains are unreliable and generally take place during summer monsoon season in this climate. Most of the North and Northeast India experiences Subtropical humid climate. Summers are very hot, while in winters, the temperature can plunge to as low as 0°C. Rainfall mainly occurs in summers but snowfall or occasional rainfall in winters is also witnessed in some areas. India has a few regions with at prominent altitudes, this mountain region experiences very different weather than the rest of the regions. The temperature falls

by 0.6°C for every 100 m rise in altitude in the Himalayas and results in a number of climates from tropical to tundra. There is less rain in the leeward side of the mountains whereas heavy rainfall is received by the well-exposed slopes. Heaviest snowfall occurs between the months of December to February.

Considering the above summary of diverse weather experience across India, it is difficult to consider temperature and rainfall averages and make any practical predictions based on them. That is the primary constraints and shortcoming of this thesis exploration. I have considered the weather counts taken at around 370 multiple stations across India to average them for any particular month. Although, it would be difficult to base any predictions for a specific place or a region based on these averages. Without current time constraints, this exploration could be further extended to a more in-depth iteration in further to address a specific location at a particular time of the year.

As per the availability of the data is concerned, I could not find data for months of January through May for the year 2014 on any of the data sources mentioned earlier. I wrote to the key authorities listed on the DGCA website regarding the acquisition of this missing data on these months, ultimately, everyone pointed me to the same data sources which did not help with the case.

CONCLUSIONS

With years and increasing population of India, more and more people are taking flights to travel domestically. This means flight cancellations will impact more people each year. Weather is one of the contributing factors towards the flight cancellations. The average temperature and rainfall in India are gradually decreasing every year. Indian summers are getting hotter and monsoons are experiencing inconsistent and an uncertain rainfall in different regions of India. Worsening weather conditions are also giving births to dire situations such as floods, droughts, and even cyclones. The contribution of weather towards flight cancellations increases in high-temperature months during Indian summers and a few following months that overlap with the monsoon season. This means that with worsening weather, it's a contribution towards flight cancellations is going to increase gradually. The aviation industry itself contributes to climate change. It's a vicious circle.

The next steps would involve looking into the diverse climatic conditions across India by considering each state or a smaller region in India, considering populated cities and highly frequented airports for further analysis. This exploration is an attempt at looking at the situation through passenger's point of view and assisting them, to a certain extent, in making well-informed travel decisions about their upcoming travel plans to avoid an inconvenient flight experience.

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