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A DEEP ANALYSIS INTO FLIGHT DELAYS' PROBLEMATIC: TENDANCIES, ROOT CAUSES AND ULTIMATE IMPLICATIONS

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Abstract:

A Deep Analysis into Flight Delays' Problematic: Tendencies, Root Causes and Ultimate Implications

Airline industry has been experiencing a considerable increase in demand over the years. However, one of the biggest challenges currently faced by airlines is the industry's inability to adjust the supply to demand's growth, as increase in airports' capacity is limited. Such result in a higher capacity utilization and, consequently in an increased disruption in processes, being flight delays the main problematic arising from that. Considering this, this study will statistically analyse multiple factors, reaching conclusions on flight delays' tendencies, root causes and implications, in order to ultimately provide recommendations to minimize such problematic by turning processes more efficient.

Keywords: Operations Management, Process Analysis, Airline Industry, Flight Delays, Performance Objectives

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Context:

Airline Industry:

Airline industry is a sub-sector of the aviation sector and englobes a range of business known as **airline companies** which can be defined as companies that supply air transportation services for both passengers and cargo from multiple origins to multiple target destinations. The service provided is in general judged by **accuracy, timeliness, quality, functionality**, and **price** which translates into on-time flights, flexible schedules, proper baggage handling, satisfactory in-flight services, safety and convenient ticket purchases (Yu, 1998). It is an industry that has been experiencing growth, moving millions of passengers and tons of cargo every year.

Airlines are inserted in a very competitive market which brings unquestionable benefits to customers but, on the other hand, informed costumers present challenges to airlines, as they require better services, higher quality, and lower fares (Yu, 1998). To meet such challenges airlines spend an enormous amount of resources to create profitable and cost-effective fare classes, aircraft routes, flight schedules, fleet plans, crew pairings, maintenance schedules, gate assignments, food service plans, training schedules and baggage handling procedures (Yu, 1998). However, due to the complexity of the industry and an extremely dynamic and uncertain environment, many causes end up leading to the disruption of the original plan, culminating in contingency handling and irregular operations, which can be translated into a major problem affecting airline industry: **flight delays**. (Yu, 1998). Being 'on-time flights' one of the most important criteria to judge the service, this represents a significant issue for any airline.

Airline Schedule Planning:

Airlines' flight schedule consists in a list of flights, with the locations they serve and their scheduled departure and arrival times and it is done by finding the most efficient deployment of an airline's resources (Yu, 1998). After determining the schedule, resources required for its implementation are assigned. The existing interrelation between flight schedule and **resources assignment** explains why minor perturbations to resources availability can cause a major disruption in airline's ability to meet its commitments (Yu, 1998). Perturbations in airlines' schedules may come as delays, cancellations, or diversions and when they occur the challenge for airlines is finding the least cost response considering all types of costs and their different impact.

Flight Delays Problematic:

Flight delay has become a widespread problematic with studies carried out in the U.S. showing that in 2007 nearly one-quarter of all flights taken in the country were delayed. According to BTS, a flight is considered to be delayed if it is operated more than 15 minutes after the scheduled time (BTS, 2020b). Delays' negative impact was confirmed by a study, sponsored by FAA, which estimated that 2007 delays, cost airlines **$8.3 billion** (Peterson, Neels, Barczi, Graham, 2013). Moreover, studies conducted show that an increase in the demand and consequently increase in the overall number of flights will result in a more than proportional increase in delays (Peterson, Neels, Barczi, Graham, 2013). In fact, between 2002 and 2007 the number of flights increased by **40.7%,** while delays observed an increase of **106.4%** (Peterson, Neels, Barczi, Graham, 2013). The opposite happened between 2007 and 2009 when, due to the recession, the number of flights decreased by **12.9%** with delays suffering a steeper decrease - **32.8%.** This correlation can be highly associated with air traffic congestion which is known to be one of the principal constraints for the future growth of the industry (Balakrishnan, Lee, 2008). Actually, despite the fact that the study above refers only to the U.S., this is a worldwide problematic. Furthermore, delays are easily propelled throughout the entire network with original ones inducing future delays in the system as aircraft and crew may not arrive on time at their next assignment or crew may have exceeded their allowable working hours (Kara, Ferguson, Hoffman, Sherry, 2010).

Problem:

To successfully meet the increased demand for air traffic services, there needs to be an increase in the efficiency of arrival and departure operations. Maximizing this efficiency while maintaining safety is one of the biggest challenges of the industry nowadays and the ultimate purpose of this work. Aiming to answer the overall question of *"what are the tendencies of flight delay problematic, its root causes and ultimate implications for airlines?"* this paper goes deep in the analysis of flight delays and presents some potential solutions for this problematic.

Literature review:

Airports' Capacity and Flight Delays:

Airport and air traffic congestion were usually given as primary causes of flight delays with airport runaways suffering from an "incentive to over-use a resource when its benefit exceeds the cost" (Rupp, 2007). Moreover, **congested airports** are more subject to disruption from random events.

Demand for air travel is increasing and it is projected to continue growing. However, the supply of airport runaway capacity will probably remain more constant as capacity growth in airports is limited. Theoretically, airline competition will be greater if a capacity-constrained airport is expanded. Such competition is responsible for reproducing fares charged and frequencies offered (Dray, 2020). Airports Commission analysis states that fares in the UK could be **10%** higher at constrained airports than at airports with no capacity constraint (Dray, 2020). Here, it is important to underline peak hours' concept – at a first stage, airports approaching capacity limit will only suffer congestion at peak hours. However, some factors must be considered as the fact that the primary planned benefit of capacity expansion is to reduce delays and congestion for the already existent number of flights instead of accommodating increased demand. In fact, capacity extension can effectively solve delays problematic if it is managed in order to improve flight system predictability and reliability regarding the number of movements that are already operating (Dray, 2020). Capacity expansions are extremely expensive projects and will only be effective solving on-time performance issue, without increases in total movements.

Furthermore, a study showed that capacity-constrained airports usually utilize larger average aircraft size since they may experience lower levels of airline competitive behaviour, manifested by the ability of increasing flight frequency on busy routes (Dray, 2020).

Flight delays' costs:

Delays in the industry come not only as a cost for airlines but also for the economy as a whole. The fact is that not only delays result in **direct costs** such as extra crew costs, fuel and emission charges, maintenance costs, passenger compensation costs and other, but also in **indirect ones** which encompass the lost business productivity regarding business travellers and the opportunity cost of time regarding leisure travellers (Peterson, Neels, Barczi, Graham, 2013). While the mechanism behind direct costs is the additional inputs required for airlines to be able to provide the same or even reduced level of output, indirect costs mentioned may result in a decrease in the demand for an airline and propel bad reputation. Moreover, such indirect costs will impact other stages/industries with the potential loss of labour productivity and change in consumer spending on travel and tourism services and goods (Peterson, Neels, Barczi, Graham, 2013). Furthermore, potential increases in airfares, resulting from the consequent increase in airlines' costs can affect consumers and consequently demand. As a matter of fact, research showed that the U.S. net welfare could increase by **$17.6 billion** for a **10%** decrease in flight delay and **$38.5 billion** for a **30%** decrease (Peterson, Neels, Barczi, Graham, 2013).

Figure 1 describes the five categories of the direct costs of flight delays (See figure 1 - appendix). The costs mentioned can be divided into different types regarding three different segments of the flight: **delay on the ground at the gate**, **delay while taxing at either airport** or **delay while airborne.** These different delay types are each associated with different delay costs, being their efficient management essential. Hence, some solutions have emerged in the industry throughout the years to tackle this fact, being the Ground Delay Programs/Ground Holding Policy one of the most used ones. This technic consists in holding on the ground a limited number of flights at their departure airport to avoid airborne delays and to have a better match with the capacity of the system (Brunetta, Guastalla, Navazio, 1998). The importance of this method is well recognized since holding aircrafts at a gate comes at a much lower expense and is safer than airborne holds. Moreover, it allows for a better management of the system. However, despite being an effective way of addressing the problem (following the theory that the extent of delay costs varies according to the segment of the flight in which it occurs), this solution is still not perfect and does not eliminate all delay costs.

It is also worth mentioning that many of these costs may depend on the departure airport, type of aircraft and differences in policies. For instance, the EU airlines incur in far higher passenger compensation costs than the U.S. ones due to the EU Passenger Bill of Rights. Moreover, aircrafts in the U.S. spend more time taxing out than in the EU and Air Traffic Management in the U.S. imposes greater ground delay programs. In sum, reports state that, on average, en route delay is greater than ground delay for European flights (Kara, Ferguson, Hoffman, Sherry, 2010).

Flight delays' Causes:

An empirical study states that air traffic congestion caused by airline hubbing and over-scheduling of flights at airports are the most common cause of flight delays (Rupp, 2007). For the purpose of this work, data from BTS will be used as a good proxy for the worldwide data. Airlines report to BTS delays' and cancellations' causes selecting broad categories, being them: **air carrier delay** - delay was due to factors that are under airline's control such as maintenance or crew problems, baggage loading, fuelling, aircraft cleaning, among others; **aircraft arriving late** - misaligned crew/aircraft due to previous delayed flight; **security delay -** mechanical problems with the aircraft, evacuation of a terminal concourse, inoperative screening equipment or long lines in excess of 29 minutes at screening areas, reboarding of aircraft due to a security breach; **national aviation system delay (NAS) -** schedule disruption as Ground Delay Programs or Air Flow Programs, delays due to a broad set of conditions such as airport operations, heavy traffic volume, air traffic control; **extreme weather** - actual or forecasted significant meteorological conditions that prevents the operation of a flight such as blizzards, tornadoes, hurricanes (BTS, 2020c).

In 2019 aircraft arriving late was the top cause of delays **(40%),** followed by air carrier delay **(31%)** and, in third, national aviation system delay **(24%),** with extreme weather and security having a far lower percentage **- 6%** and **0%** respectively (BTS, 2020c). BTS also makes an important caveat for the reason why extreme weather has such a low percentage. In fact, this category corresponds to the type of extreme weather that prevents flying and within NAS there is another weather category that slows the operations but does not prevent flying. Delays or cancellations referred to NAS are the type of weather delays which could be reduced by the usage of corrective actions by the airports or the Federal Aviation Administration. This separation was done, since the Air Carrier On-Time Reporting Advisory Committee believed that establishing a difference between extreme weather delays and weather delays that could be resolved by improvements to the system would provide a better picture of the extent of weather delays and system managers' would have better information to make improvements. As an example, in 2019 **56.8%** of NAS delays were caused by weather (BTS, 2020c). Furthermore, weather is a major problem regarding this problematic since it significantly reduces the capacity of airspace and runaways, with weather forecasts being used by air traffic management to estimate the resulting reduction in capacity.

Additionally, some drivers of delays as weather and aircraft arriving late are exposed to seasonal fluctuations as bad weather is often observed in the Winter and aircraft arriving late is more common in high season. This is confirmed when delay rates are observed monthly (Rupp, 2007).

Process definition and process in airlines:

Being process characterized by a sequence of activities that aim at adding value to the costumer, it is possible to divide it in: central process – involved in the direct production - and supporting process - ensuring the functioning of central process and overall operations. Production is done by changing inputs into outputs through the so called "input-transformation-output process", being inputs the resources and outputs the final goods or services. Transformed resources can be in the form of **materials** (transforming their physical properties), **information** (transforming their informational properties) or **costumers** (changing customers physical properties – airlines transform the location of their costumer). Although the three can be applied to the same operation, one of them is often dominant. Mass rapid transportation, where airlines are inserted, processes predominantly inputs of costumers (Slack, Chambers, Johnston, 2010).

It is also important to distinguish products from services. Products are usually tangible and services intangible. Moreover, services tend to have a shorter stored life. In the case of airlines the output delivered comes essentially in the form of **services** (Slack, Chambers, Johnston, 2010).

In sum, some inputs used by airlines are aircraft, pilots and air crew, ground crew, passengers and freight, while some of their operation processes are check passengers in, board passengers, fly passengers and freight and care for passengers and some of the operation's outputs are transformed passengers and freight (Slack, Chambers, Johnston, 2010). Any disruption of inputs or processes may lead to delay problems.

Important Process' Phases:

There are different process' phases that should be considered in an operation such as: **process design**, **planning and control** and **process improvements**. Firstly, **process design** must deliver a solution that will work in practice, should reflect process objectives, and involves the identification of all the individual activities, deciding the sequence in which they are performed (Slack, Chambers, Johnston, 2010). It can be defined as "the process by which some functional requirement of people is satisfied through the shaping or configuration of the resources and/or activities that compose a product, or a service, or the transformation process that produces them" (Slack, Chambers, Johnston, 2010). Secondly, **planning and control** is about managing the ongoing activities of the operation. **Planning** is concerned with what is intended to happen in the future but does not guarantee that it will actually happen while **control** is about coping with changes which may implicate some intervention in the original plan (Slack, Chambers, Johnston, 2010). Therefore, it is easy to link the importance of this phase with flight delays. Finally, **process improvement** generally regards how an operation can perform better and how to bring improvement activities together (Slack, Chambers, Johnston, 2010). There are many approaches to improvement such as Lean, Six sigma and Total Quality Management, among others. Applying this phase to the airline industry regarding flight delays is the ultimate goal of this work.

Five Operations Performance Objectives:

An important part of Operations Management is the five operations performance objectives: **quality, speed, dependability, cost, and flexibility** (Slack, Chambers, Johnston, 2010). Firstly, being **quality** the consistent conformance to costumers' expectations and the production of services to specification, it is easily deduced that flight delays have a negative impact on the quality delivered by an airline. This represents a real problem as quality is a considerable influence on customer satisfaction and has both an external impact, influencing their satisfaction and an internal one, leading to stable and efficient processes (Slack, Chambers, Johnston, 2010). Furthermore, one can also perceive how delays affect **speed**, being it characterized by a fast response to external costumers. In aviation, this objective can be described as the time between the schedule time for a flight and costumer reaching his/her destination. Moving on to **dependability**, since its essential meaning is "doing things in time for costumers to receive their services exactly when they are needed, or at least when they were promised", delays are a major problem when meeting this objective (Slack, Chambers, Johnston, 2010). As an example applied to the industry, no matter how cheap or fast a flight is, if the service is always late, costumers will be less likely to select it. In fact, punctuality is crucial for a favourable dependability. Moreover, flight delays cause airlines to incur in different types of extra **costs**, which can also be linked to the problem of increased prices and lost demand since increased cost of service production can lead to higher prices to the costumers to maintain gross margin. Finally, **flexibility** on the contrary of the others, is not negatively affected by delays itself but instead, it is an objective that can help solving the issue, since flight delays may occur under unpredicted conditions. Flexibility is the ability to change the operation in some way. High agility may imply a better response of an operation to uncertainty and fast services may depend on operations' flexibility (Slack, Chambers, Johnston, 2010).

Methodology:

Having the present work the objective of better understanding flight delays problematic, a practical research analysis was conducted to firstly corroborate the theory found on literature review and secondly extend such findings to obtain a more complete analysis of the topic. Such culminated in the providence of recommendations to address the issue being studied.

The study mainly consisted in the **collection of different data** that was subsequently **statistically analysed** and included relevant factors as: total number of flight operations, percent/total number of on-time flights, percent/total number of delayed flights, percent/total number of cancelled flights, the dissertation of the percentage of flight delays by causes, total delay minutes, total number of passengers, revenue passenger-miles values, total number of consumer complaints, net income of different airlines, airports' data, among others. Data was collected with different periodicities including yearly, quarterly, and semi-annual.

BTS, being part of the Department of Transportation, was the data base used for the collection of the data (BTS, 2020d). BTS assures the credibility of the data provided through rigorous analysis, transparent data quality and independence from political influence (BTS, 2020a). The source contains mainly information regarding the U.S. industry therefore, the study mainly focussed on the **U.S. airlines' domestic activity**. Such was considered a big enough sample and a good proxy for the worldwide industry since U.S. is a major market for air transportation and is constituted by multiple airlines. Moreover, SATA Air Açores also provided daily data from 2016 to 2019 for several factors mentioned. Despite the data being provided separated by international flights and Azores' flights, analysis was conducted with the total conjoint of the data since, by being part of the same company's operations, their effects are interrelated. Furthermore, Federal Aviation Administration data was also used and additionally to the data, articles and studies were used to complement the analysis. (FAA, 2020).

The study conjugated two approaches: an overall analysis of all the conjoint data from the U.S. industry to analyse overall tendencies, rood causes and implications from a global perspective, and a case studies approach trough the analysis of two specific airline companies' data, one also inserted in the U.S. market – JetBlue Airways – and other inserted in the European one – SATA Air Açores. These case studies approach complemented global findings, allowed for a more concrete analysis, and raised clues by studying evolutions of particular airlines.

In statistical models' analysis, it was considered significant levels smaller than 0.05 and adjusted R squared was interpreted as well as Dfbetas.

Analysis and Results:

<u>Global Growth in Air Travel:</u>

As stated in the methodology, from the data collected from BTS and SATA we conducted several statistical analyses regarding many parameters of flight delays in the time period from **2012 to 2019** – for the U.S. airlines – and from **2016 to 2019** – for SATA Air Açores. Firstly, one important fact that was intended to be proved was the tendency for the increase in the total number of flights. For that we retrieved each year's total number of flights and calculated the percentual difference between the first and last year from the period being studied. Results obtained showed that from 2012 to 2019 total number of domestic flights of **all U.S. carriers** increased by **21.7%.** The same tendency was found when focusing on one particular airline – **JetBlue Airways** – with its total number of domestic flights increasing by **29.8%** for the same time period. Moreover, by extending our analyse outside the U.S. results showed that the total number of flights of **SATA Air Açores** registered an increase of **12.4%** from 2016 to 2019. This tendency can be justified based on the observed growth of global air traffic passenger demand. In fact, when we conducted the same statistical analysis for the total number of passengers, we found an increase of **26.3%** in the number of passengers flying from **all U.S. carriers** between 2012 and 2019 (Figure 2 - appendix). Again, for **JetBlue Airways** we registered an even larger increase – **35.7%** - which is in line with the mentioned percentages for the increase in the number of flights since JetBlue also had a higher percentage regarding such factor (Figure 3 - appendix). As for **SATA Air Açores**, we also statistically verified a **15.4%** increase for this parameter (Figure 4 - appendix).

Our results are supported by a source, where it is possible to observe this growth from a worldwide perspective. According to Statista, annual growth in global air traffic demand has always been positive from 2006 to 2020 except for 2009 – possibly due to the effects of the recession – and 2020 due to Covid-19 Pandemic (Mazareanu, 2020a). Also proven by Statista is the ongoing global growth in air travel, which can be explained by three main facts: firstly, the observed increase in low-cost carriers – which have nearly doubled their market share over the last 15 years - , secondly the observed growth of the global middle class which increases the number of consumers willing to afford air travel and finally, the growth in airport infrastructure spending, increasing global capacity (Mazareanu, 2020b). Being JetBlue a low-cost carrier, we can assume that this stated increase in low-cost carriers' market share can justify why the percentages we obtained for the increase in the number of flights and passengers were higher regarding this airline than the ones regarding the set of all U.S. carriers.

Delay Causes:

Secondly, we analysed the causes of flight delays by collecting yearly data on the breakdown of delays' percentage between the different delay causes. Our results showed that from the five categories presented in literature review, three of them have always led, both in terms of the number of delays and total delay minutes being them **late aircraft arrival, air carrier** and **NAS**. In general, regarding the set of **all U.S. carriers**, it was evident that **late aircraft arrival** was the most problematic cause not only in terms of frequency of its occurrence, but it was also the one that corresponded to a higher total delay minutes (Figure 5 and 6 - appendix). Again, if we focus our analysis in **JetBlue Airways**, similar results were found (Figure 7 and 8 - appendix).

By linking this with the tendency for higher levels of flight delays observed, we may interpret that since a higher number of flights increases the complexity of the network, congestion, and capacity utilization rate, this may also result in higher probabilities of aircraft arriving late, partially explaining the increase in delays. In fact, from the graphs we created for "increase in delayed flights" (Figure 9 and 10 - appendix) and the one regarding the causes (Figure 5 and 7 - appendix), it is possible to see that the function for **late aircraft arrival** follows nearly the same path as **delayed flights**. The same happening with **air carrier**. This may be explained by the fact that a higher network complexity requires higher alignment and better management techniques within airlines and airports and when poorly done, it may be reflected in these two causes.

To statistically prove that air carrier and late aircraft arrival causes of delay are somehow related with the increase in total number of flights, we conducted **linear regression** analysis with annual data for total number of the U.S. domestic flights, late aircraft arrival and air carrier as a percentage of total delayed minutes (from 2004 to 2019). For accuracy effects, we proved that the model regarding air carrier cause is statistically significant with a p-value of 0.04 (Figure 11 – appendix). Therefore, we can state that approximately **42% of the increase in air carrier cause** are explained by the increase in the total number of the U.S. domestic flights (Figure 12 - appendix). Moreover, we also proved the significance of the model for late aircraft arrival cause, having it a p-value of

0.027 - **30% of the increase in late aircraft arrival cause**, are explained by the increase in the total number of U.S. domestic flights (Figure 13 and 14 - appendix).

In fact, primary delays caused by one aircraft are likely to originate knock-out effects in the rest of the network causing secondary delays. This is easily observed by the cause of **aircraft arriving late,** among others. Therefore, delay costs are scaled up to the network level. Moreover, the extent of secondary delays is usually worse for longer primary delays and for primary delays occurring early in the operational day since knock-out effects in the network are greater (Cook, Tanner, Jovanovic, Lawes, 2009). The key for the minimization of this network effect is in airlines' ability to recover from the delay. In 2007 European reactionary to primary delay ratio was **0.8** - for one minute of primary delay, on average, 0.8 minutes of secondary delay are caused in the network (Cook, Tanner, Jovanovic, Lawes, 2009). Such ration has worsened since 2003 and EUROCONTROL (2008) proposed that the increase in sensitivity to primary delays is probably due to the higher observed levels of aircraft and airport utilization, which is, in turn, a result of the strong traffic growth analysed.

Correlation between number of flights and number of delays:

Moving on, from data collected we could also corroborate the impact that the increase in the number of flights has in flight delays. By analysing yearly data for the number of delayed flights, we found that from 2012 to 2019, the percent increase in delayed flights of the **U.S. carriers** was **36.9%** and **64,9** for **JetBlue Airways**. Such are higher percentages than the ones we found for the increase in number of flights – **21.7%** and **29.8%,** respectively. Extending our study for **SATA Air Açores**, such relationship was also confirmed with a **122.32%** increase in percent of delayed flights from 2016 to 2019. If we observe these fluctuations yearly, this correlation is also detected, however in a slighter way. For longer periods of time the impact observed is larger with the relationship between the level of air travel and levels of flight delay being obvious. Through figures 15, 16 and 17 (appendix), we are able to yearly observe such correlation. Additionally, figures 18, 19 and 20 (appendix), illustrate the changes in the percentage of delayed and cancelled flights during the time period studied.

To estimate and corroborate this relationship between the level of air travel and delays we conducted a **linear regression analysis** with semi-annual data on the total number of domestic flight operations and the percentage of flights delayed from the second semester of 2003 (Jul – Dec) to the first semester of 2020 (Jan – Jun). Results obtained validate the relationship as we proved that the model is statistically significant, with a p-value well below 0.05 and it proposes that approximately **33% of delayed flights are explained by the total number of flight operations** (Figure 21 and 22 - appendix). Furthermore, as we computed **DfBeta** it was possible to conclude that the first semester of 2020 was the observation that had most influence in the model, with its value being approximately **1.2** – the highest one. Moreover, by running a graphical analysis we found that this observation was an outlier, which is explained by **Covid-19 Pandemic** (Figure 23 - appendix). As a complement, we conducted the same linear regression analysis using quarterly data from September 2003 to April 2020 and again, with a p-value well below 0.05 we proved the model to be significant (Figure 24 - appendix). However, by doing the same graphical analysis, we found that the first four-month period of 2020 is still an outlier regarding the percentage of delayed flights although the total number of domestic flight operations have not decreased accordingly, since covid-19 effects in the U.S. were not drastically noted in the first months of the year (Figure 25 - appendix). Thus, we can explain the decrease in the percentage of delayed flights through the decrease in the number of international flights that was already occurring in that period. This decrease in international flights may have decreased airports' congestion. In fact, from data retrieved we found that January to April 2020 the number of international flights decreased by **37%.**

11 September/Covid-19 Effect on Delays:

As already stated, a possible justification for such correlation is that the increase in the number of flights of an airline lead to congestion problems at peak hours of operations in some airports and probably to a more complex network. To complement the analysis, specific events were studied:

As we statistically analysed data collected, we concluded that from January to June 2020 the number of domestic flights scheduled in the U.S. has declined **29.9%** while the number of delayed flights decreased by **64.9%** compared with the same period of 2019 due to **Covid-19 Pandemic**. In fact, the percentage of late flights for such period of 2020 was only **9.91%,** contrasting with a percentage of **19.79%** in 2019. Moreover, by running a graphical analysis (Figure 26 - appendix) we can monthly analyse this phenomenon and a major gap is noticed, specially from March until June, which coincides with the months were quarantine started, causing a drastic reduction in the number of flights. Additionally, by comparing delay causes' percentages, we found that **late aircraft arrival** and **air career** were the ones experiencing a major decrease, which may corroborate the referred correlation between these causes and higher levels of congestion and network complexity (Figure 27 and 28 - appendix). Moreover, we noted the increase in cancelled flights - 2.35% (2019) to 10.39% (2020) - connected with the Pandemic effects.

However, on normal conditions, passenger air travel was expected to keep the positive growth rates in 2020 (Mazareanu, 2020a). Covid-19 is worldwide foreseen to offset aviation industry by a 54.2% decrease in passengers, making it the first airline's sector negative financial performance since 2009, with a considerable net profit loss (Mazareanu, 2020a). Moreover, crisis that may arise due to the Covid-19, can also affect the growth of aviation in future periods.

Furthermore, a report concluded that **following terrorist attacks of September 11th**, 2001, a reduction in the demand for air travel was observed with domestic scheduled flights in the U.S. decreasing by **700000** in 2002 when compared with 2001. This led to an improvement in airline on-time performance (Rupp, 2007). The demand was restored in 2003 and 2004 and the increase has also brought back airport congestion with the proportion of late arrivals returning to its historical average (Rupp, 2007).

Time of the Day Effect on Delays:

To study peak hours' effect on delays and whether they vary accordingly with the time of the day, we analysed data from five days of January 2019 regarding schedule and delayed arrivals. Through figure 29 (appendix), we can deduce that delays are more concentrated from 8am until 11pm, being it a trend that is verified in every of the five days studied. Once again, this trend follows the number of schedule arrivals, which are higher in such peak hours (8am – 11pm).

Airports' Capacity and Flight Delays:

Usually, expanded airports experience a short-term decrease in average delay as it was found by Hansen et al. (1998) for **DFW airport** (Dray, 2020). However, the reason behind such a short-term effect may be the fact that in a long-term additional capacity may be filled with new flights, allocating additional growth. It is important to distinguish between airports with a general high Capacity Utilization Index (CUI) and airports with lower CUI but with peak-hour movements approaching or exceeding capacity. In this last case, airports are more moderately constrained and additional growth will probably come from adding flights at non-peak hours (Dray, 2020).

To analyse this, we collected data from three U.S. large hubs airports (**ATL, DTW, SLC**) - being **ATL** in the top of the busiest airports in the U.S., experiencing high congestion, **DTW** with medium congestion, but still being considered a busy airport, and **SLC,** experiencing low levels of congestion. We concluded that, from 2004 to 2019, **ATL** was the airport experiencing the highest percentage of delayed flights, followed by **DTW**, leaving **SLC** with the lowest percentages (Figure 30 - appendix). Moreover, **ATL** had an expansion project started in 2000 and completed in 2015, with its fifth runaway being opened in 2006 – in figure 30 (appendix) it is possible to see the decline in percent of delayed flights at **ATL** from 2006 onwards. However, its short-term effect can be also confirmed with the stagnation and slightly increase of the percentage in later years. As for **DTW,** it opened a new runaway in December 2001.

To complement the analysis done with previous studies, Dray (2020) reinforces that **Atlanta Airport's** 2006 - expansion had, as its main impact, a small increase in flight time predictability and **Frankfurt Airport's** 2011 fourth runaway resulted in a **14%** increase in on-time arrival performance. From 2000 until 2016, **55 of the top 150 airports**, as ranked by scheduled flight departures, in 2015, either added runaways or were replaced by higher-capacity airports, being it dominated by North America, Europe and Asia (Dray, 2020). Many expanded airports remained constrained even at post-expansion capacity (Dray, 2020). However, by maintaining the same number of total movements, capacity expansions can allow for the implementation of better schedules for more efficient hubbing.

Previous Years Results:

To better understand the changes occurred in the industry by retreating a longer period of time, we analysed data from 2004 to 2007 and some major differences were noticed. Firstly, a difference was observed between the pattern followed by the set of **all U.S. carriers** and **JetBlue Airways** – while the growth in the **total number of flights** has been always observed for JetBlue Airways, being the values from the time period 2004 – 2007 well below the ones from 2012 – 2019 (Figure 31 – appendix), the same did not happen regarding the set of **all U.S. airlines** since total number of flights actually decreased between the same interval (Figure 32 – appendix). A possible justification for this is, once again, the notable gain in market share of low-cost airlines. Moreover, we can suggest that 2007-2008 financial crisis may have impacted the overall demand for the following years and while low-cost airlines were gaining power, other may have suffered from the opposite. In fact, when we analysed it from a different perspective, observing data for the **total number of passengers,** we found that even for the set of **all U.S. carriers**, the number of passengers has always increased, except for the time period between 2007 and 2009 (Figure 33 - appendix), the same happening for **revenue passenger-miles** (Figure 34 - appendix). However, the total number of flights decreases for a longer period of time, which may suggest that there was a change in capacity utilization with passengers migrating from certain airlines to others or an increase in some airplanes' capacity. Moreover, since the number of passengers is a more suitable variable for defining the demand than the number of flights, it is worth mentioning that form 2004 until 2019, the number of passengers for **all U.S. airlines** suffered an increase of **28.9%.**

Regarding these years we also found a major difference when analysing data from **delay causes**. From 2004 to 2007 **NAS** was within the two major causes exceeding **Air Carrier**. We observed this for both the set of **all U.S carriers** and **JetBlue Airways** (Figures 35, 36, 37 and 38 - appendix). Therefore, from this time period to the one studied above (2012-2019) there was an undeniable increase in **Air carrier** cause, contrasting with the decrease in **NAS**. From this, we can conclude that until 2007 a high percentage of delays were a result of the inability of the aviation system to handle growth traffic demands, while from 2007 onwards, delays resulting from airline internal problems gain force.

Costs:

To analyse costs' component, we ran a graphical comparison of the evolution of **cost of delay, minutes of delay** and **number of flights delay**, and we were able to see that, as expected, change in **cost of delays** follows the path of both change in **minutes of delay** and change in **number of flights delay**. However, thought figure 39 (appendix) we can verify that it is more dependent on the **total minutes of delay** than on the total **number of delayed operations**, which is reasonable, since the longer the delay the more costly it is.

Furthermore, we analysed data from **SATA Air Açores,** regarding costs incurred due to delays and cancellations from 2016 to 2019. Again, a **positive tendency** was observed, which was aligned with the total number of flights. Through the analysis of figure 40 (appendix) we found the same results for the correlation between cost of delay, minutes of delay and number of flight delay. Moreover, costs incurred were divided into three categories: **meals**, **accommodation** and **compensation**. Our analysis showed that compensation is the largest component, standing out widely from accommodation and meals components (Figure 41 - appendix).

Additionally, to expand the analysis for costs, some previously done studies were analysed. FAA sponsored the Brattle Group and the five NEXTOR universities to conduct a study on delay impact in the U.S., which estimated a total cost of **$31.2 billion** for all U.S. air transportation delays in 2007, being **$8.3 billion** regarding airlines component (Ball, Barnhart, Dresner, Hansen, Neels, Odoni, Peterson, Sherry, Trani, Zou, Britto, Fearing, Swaroop, Uman, Vaze, Voltes, 2010). By utilizing regression models to extrapolate 2007 values, FAA has conducted cost estimates for **2016, 2017, 2018** and **2019** (FAA, 2019): (See figure 42 - appendix). The total cost of delay is divided in four components: **airlines, passengers, lost demand** and **indirect**. It was found that regarding airlines component, the costs, encompassing increased operating expenses, should be associated with two sources: **schedule buffers** and **unforeseen delays,** since both sources present additional costs and represent poor operational performance (FAA, 2019). As for **schedule buffers**, typical pilot contracts state that they are paid based on the greatest of scheduled block time and actual block time. Moreover, longer scheduled times results in poorer aircraft utilization and larger fleets. On the other hand, **flight delay** can be truly disruptive, since airline fleet and crew schedules are based largely on the schedule times. Costs associated with these two sources represent possible cost saving from a better operational performance in the case of their elimination (FAA, 2019).

Together, the U.S. airlines incur in billions of delay costs per year with a growth tendency. This growth is aligned with the previous studied growth in the total number of flights and respectively the number of delayed flights.

Moreover, there are different sets of rules concerning flight delays and cancellations that must be followed by airlines. This different sets are each applied to different zones. The incompliance of such rules can be very costly to airlines. Many have already suffered enforcement orders on flight delays and cancellations, being **British Airways, Frontier Airlines, Inc., TAP Portugal, Southwest Airlines Co., JetBlue Airways Corporation** among the dozens of airlines that have suffered a penalty from the United States of America Department of Transportation Office due to violations regarding delays and cancellations (U.S. Department of Transportation, 2020).

<u>Airlines On-Time Rank and Performance:</u>

U.S. Department of Transportation releases every month an air travel consumer report containing a **ranking of all U.S. airlines** - containing at least one percent of total domestic schedule-service passenger revenues - according with their **percentage of operations arriving on-time** (U.S. Department of Transportation, 1998-2020). We analysed the yearly rank of three different low-cost airlines – **JetBlue Airways, Southwest Airlines** and **Frontier Airlines** – to observe possible correlations. As shown in figure 43 (appendix), **Frontier Airlines** was often ranked with worse results followed by **JetBlue Airways**. Through figure 44 (appendix), we can also conclude that although they are all low-cost airlines and the three are increasing their total number of passengers, **Frontier Airlines** registers a much lower number of passengers than the other two, and once again followed by **JetBlue**. Following the same reasoning, **Southwest's** net income is also greater, with **Frontier's** one being the lowest (Figure 45 - appendix)

Moreover, through the same consumer report, we could verify that from the multiple categories of **consumers' complaints**, "flight problems" was the leader every year with the highest % of total complaints. Flight problems category englobes cancelations, delays, or any other deviation from schedule, whether planned or unplanned (U.S. Department of Transportation, 1998-2020).

Conclusions/Recommendations:

Summing up the findings obtained from the results, some major conclusions in response to the initial problem may be drawn. Firstly, aviation is a growing industry which is already causing it to **experience some congestion due to capacity constraints**. Secondly, as expected in operations' theory, findings indicate that an **increase in capacity utilization result in a poorer performance**. Moreover, it was proved that delays cost billions not only to airlines but also to a country's economy and how **punctuality ranking** can be **related to performance**. Finally, **network effects** proved to be a major issue with many delays arising from reactionary to primary delays. Based on such conclusions, recommendations were outlined.

Being late aircraft arrival and air carrier the causes of delay that are experiencing a notable growth tendency with the increase in the number of flights, such may be associated with a higher capacity utilization, particularly aircrafts' utilization rate. In fact, the same aircraft is used in several flights per day causing knock-out effects in the network, as by being late in a primary flight, subsequent flights may be also affected due to resource allocation. Therefore, **if capacity utilization rate of aircrafts were decreased by adding an additional aircraft to their network**, performance could be improved and network efficiency might increase. Adding one aircraft may be an expensive movement, however, it may also result is a persistent reduction of costs associated with delays, network efficiency and aircraft maintenance, (since an overutilization of a resource may result in a faster depreciation) among others. This costs reduction, along with a performance improvement that might also result in an increase in revenues may compensate the needed investment.

Secondly, with delays being concentrated in peak hours, due to the higher concentration of flights, **airlines could spread more evenly their flight schedules so that they can be more balanced**, allowing for a more efficient utilization of the available resources. Such will not only contribute for a more evenly resources' utilization inside the airline but also in the airports and airspace. The result increase in network efficiency and performance may exceed the cost associated with non-peak hours being less profitable.

Moreover, sensitivity to primary delays should be reduced since knock-out effects ratio is high and can result in late aircraft arrival and air carrier causes of delay. For that, airlines' ability to recover from delays must be improved. Furthermore, air carrier constitutes a growing and principal cause of delay and being it a cause that is under airlines' control, including factors as maintenance, crew problems, baggage loading, fuelling, aircraft cleaning, etc., it may indicate that teams and departments are not working efficiently, or they are not aligned. To correct such problems, a **better resources management and allocation and communication and alignment between different departments** may be needed. It is crucial for an airline to have all its departments connected and its objectives well set and understood. An efficient internal alignment is essential to increase airlines' flexibility to react to unpredictable events and its agility to change its operations.

Finally, even with delays problematic being difficult to entirely eliminate, **airlines should focus on reducing delayed minutes** since the longer the delay, the costly it is. In fact, minor delays can result in a non-existing or very minimized negative impact while a long delay may demand a high compensation and associated costs and generate higher costumer dissatisfaction since minutes of delay are possibly the best variable to evaluate the impact of delays. Moreover, longer delays will also have a higher impact on the network.

Limitations and Future research:

Despite the data analysed being considered a representative sample, leading to valid results, it is important to bear in mind that they are not as accurate as they would be with the analysis of all population's data. For instance, regarding the results of costs of delays, FAA estimates for 2016 - 2019 regard only the U.S. airlines and although representing a good approximation to other airlines' costs, some adjustments need to be done. For example, contrary to the U.S., in Europe, airlines incur in soft and hard costs resulting from passenger delay. Moreover, these airlines must comply with the regulation for EU's air passenger compensation and assistance scheme (Cook, Tanner, Jovanovic, Lawes, 2009). Furthermore, when linking airlines' on-time rank and their performance, it is also important to consider that there are many factors that can directly affect the total number of passengers and net income and punctuality rank is only one of them. It is also important to mention that data obtained from SATA Air Açores corresponds to a smaller time-period than the one extracted from BTS. Therefore, some analysis done for the U.S. and JetBlue could not be done for SATA Air Açores.

Considering all of that, as future research, results obtained should be checked for different population's samples and the analysis should be extended to other factors that may interfere with their accuracy.

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Appendix:

Abbreviations:

BTS - Bureau of Transportation Statistics

EU – European Union

ATL – Atlanta Airport

FRA – Frankfurt Airport

Figure 1 - Different direct costs of flight delays

Extra Crew costs:	**Fuel and emission charges costs:**	**Maintenance costs:**	**Passenger compensation costs:**	**Other costs:**
Extra cost paid in addition to the usual cabin and flight crew salaries/expenses: employing additional crew or additional paying to usual crew for extra hours.	Additional fuel burned in airborne delays; Extra future costs of emissions charges (According to legislation all airlines operating to or from EU airports are required to surrender permits for the CO2 emitted since CO2 emissions from aviation have been included in Eu emission trading system; All fuel used is associated with an additional carbon permit cost).	Mechanical attrition of aircraft waiting at gates, taking longer re-routes to obtain a better departure slot or subject to arrival management; Additional cost of maintaining the airframe and power plant of the aircraft.	Compensation paid by airlines to passengers in the case of delayed flights (longer delays – higher associated cost per minute).	Any other additional costs that airlines may incur due to delays such as airport charges, parking, weight payload factor, etc.

Reference: (Kara, Ferguson, Hoffman, Sherry, 2010; Cook, Tanner, Jovanovic, Lawes, 2009)

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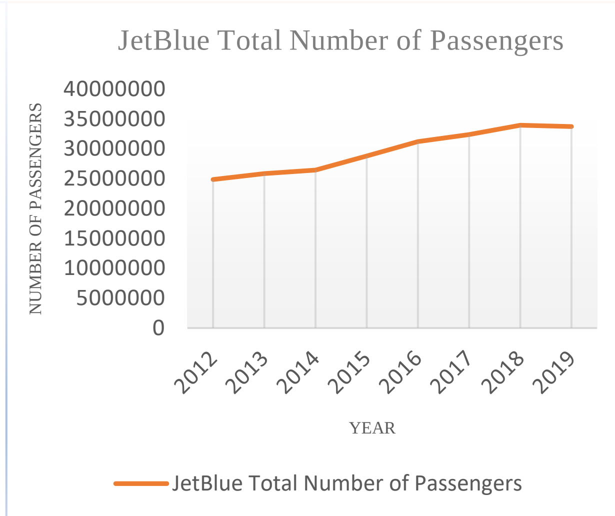

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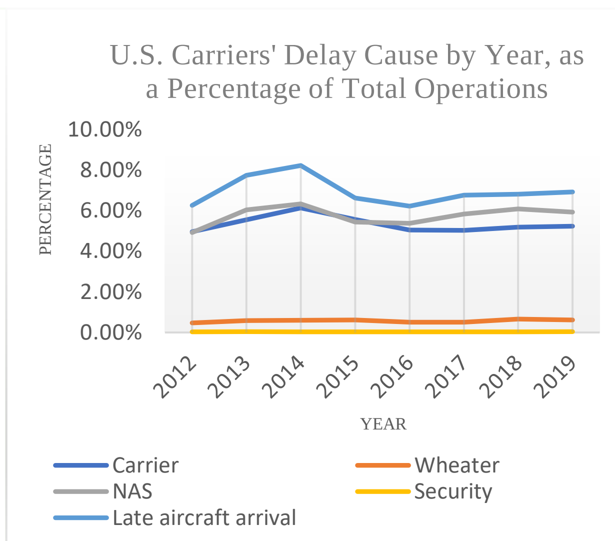

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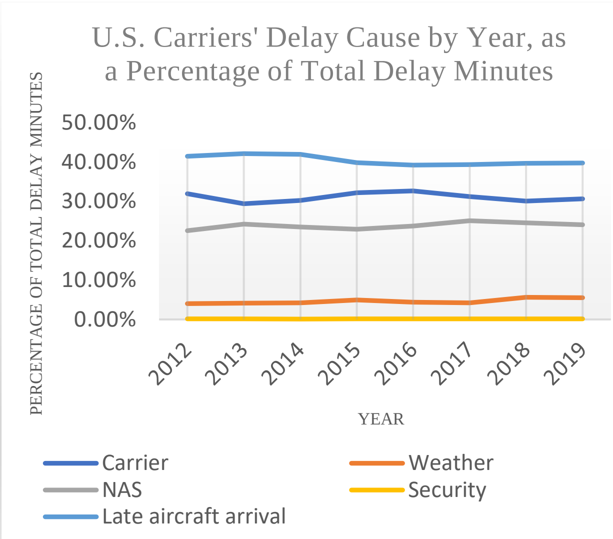

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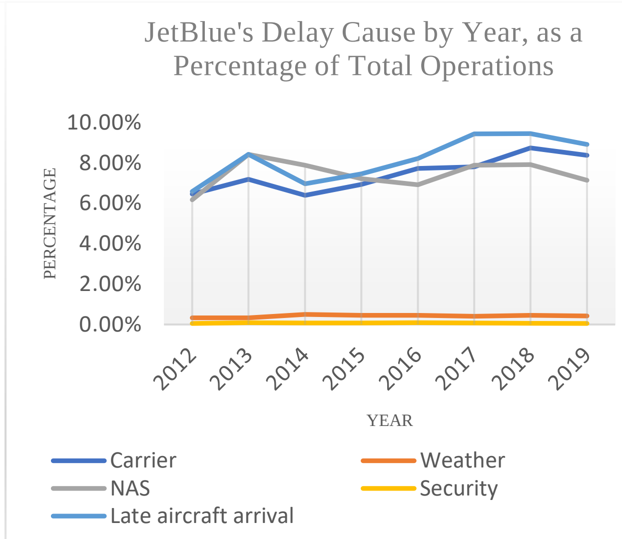

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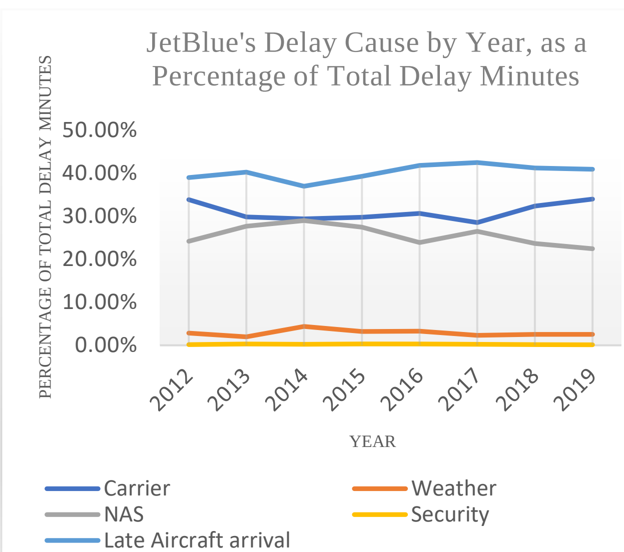

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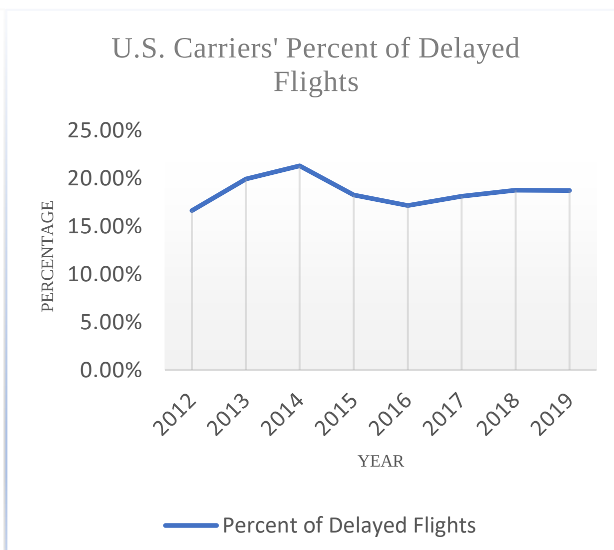

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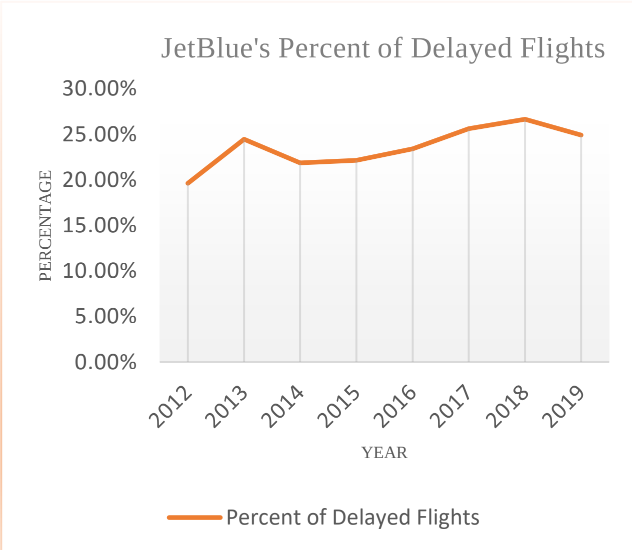

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Figure 11: Significance of the linear regression model concerning total number of U.S. domestic flights and air carrier total delayed minutes

ANOVAa

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	24.462	1	24.462	11.722	.004[b]
	Residual	29.215	14	2.087		
	Total	53.677	15			

a. Dependent Variable: Air Carrier total delayed minutes

b. Predictors: (Constant), Total Number of Flights

Figure 12: Statistical relationship between total number of U.S. domestic flights and air carrier total delayed minutes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.675[a]	.456	.417	1.44457%

a. Predictors: (Constant), Total Number of Flights

Figure 13: Significance of the linear regression model concerning total number of U.S. domestic flights and late aircraft arrival total delayed minutes

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	30.283	1	30.283	6.137	.027[b]
	Residual	69.086	14	4.935		
	Total	99.369	15			

a. Dependent Variable: Late aircraft arrival total delayed minutes

b. Predictors: (Constant), Total Number of Flights

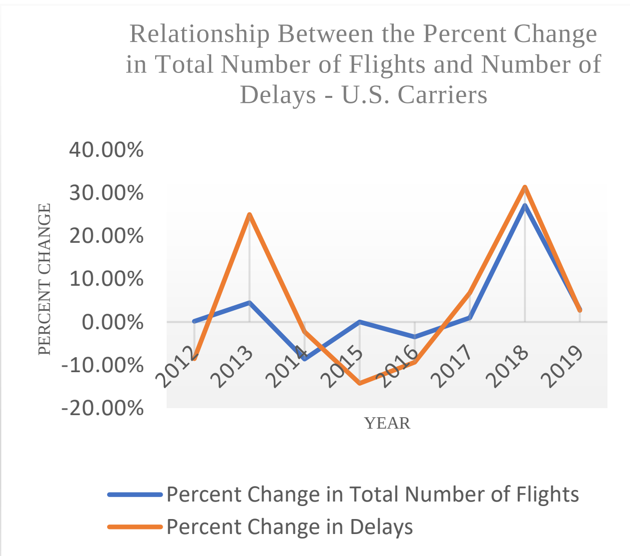
Figure 14: Statistical relationship between total number of U.S. domestic flights and late aircraft arrival total delayed minutes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.552[a]	.305	.255	2.22143%

a. Predictors: (Constant), Total Number of Flights

Figure 15:



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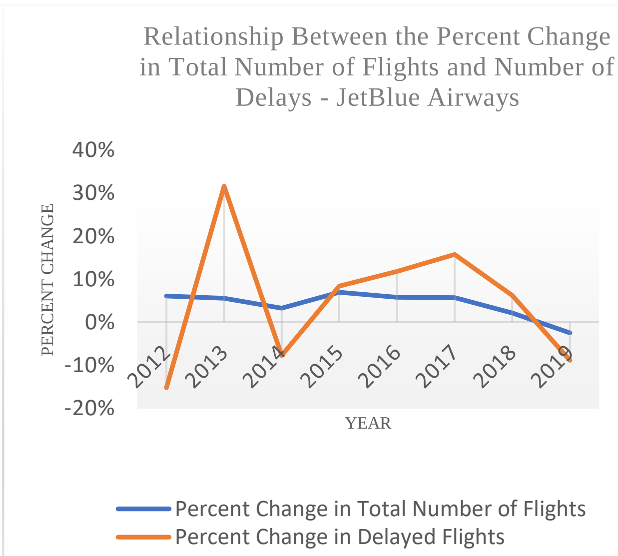

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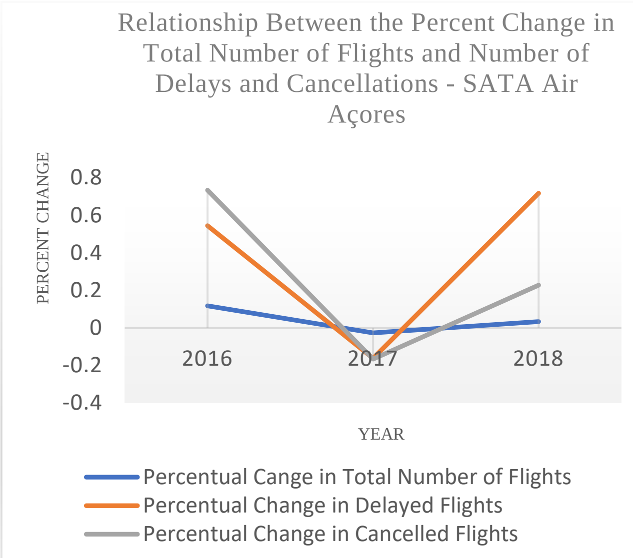

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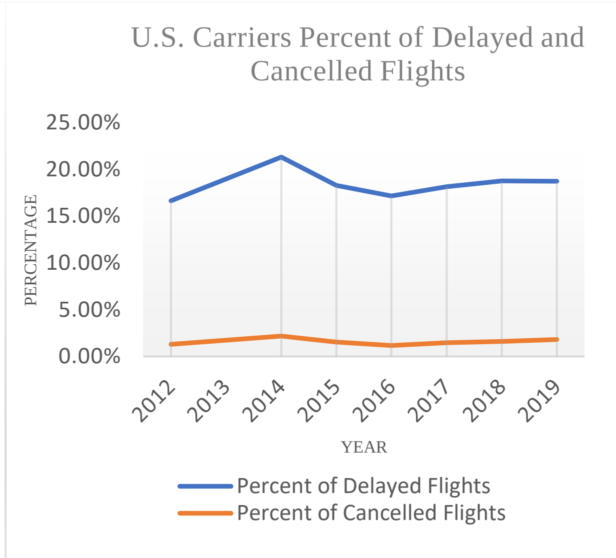

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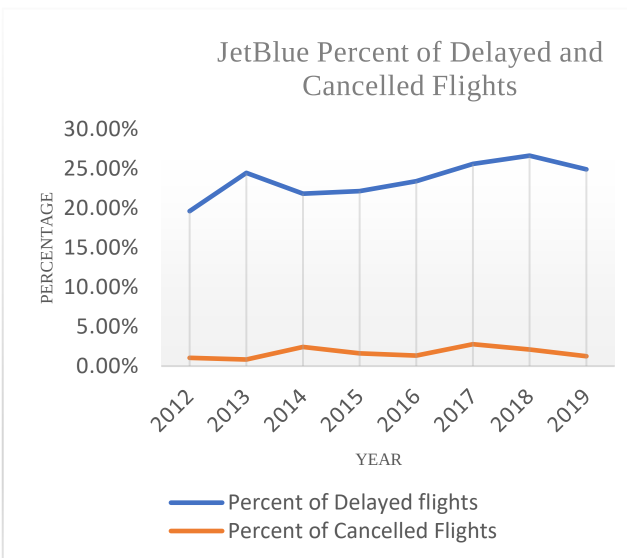

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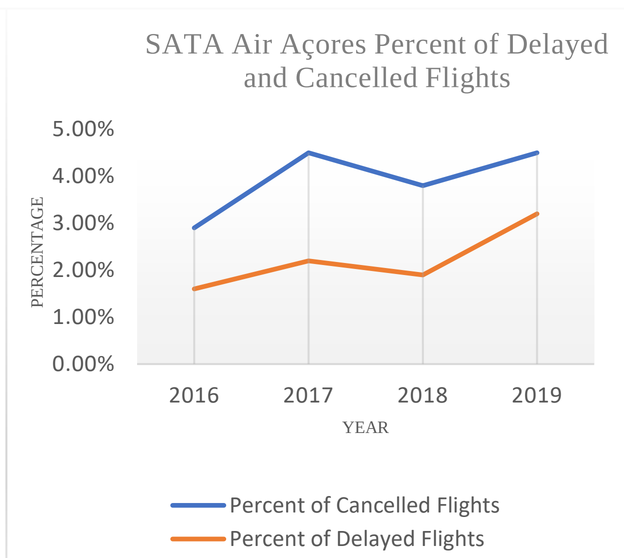

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Figure 21: Significance of the linear regression model concerning total number of U.S. domestic flights and percentage of delayed flights – Semestral data

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	92.322	1	92.322	16.932	.000[b]
	Residual	174.478	32	5.452		
	Total	266.800	33			

a. Dependent Variable: Percentage of delayed flights

b. Predictors: (Constant), Total number of flights

Figure 22: Statistical relationship between total number of U.S. domestic flights and percentage of delayed flights – Semestral data

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.588[a]	.346	.326	2.33504%	.811

a. Predictors: (Constant), Total number of flights

b. Dependent Variable: Percentage of delayed flights

Figure 23: Percentage of Delayed Flights from 2007 to 2020 – Semestral data

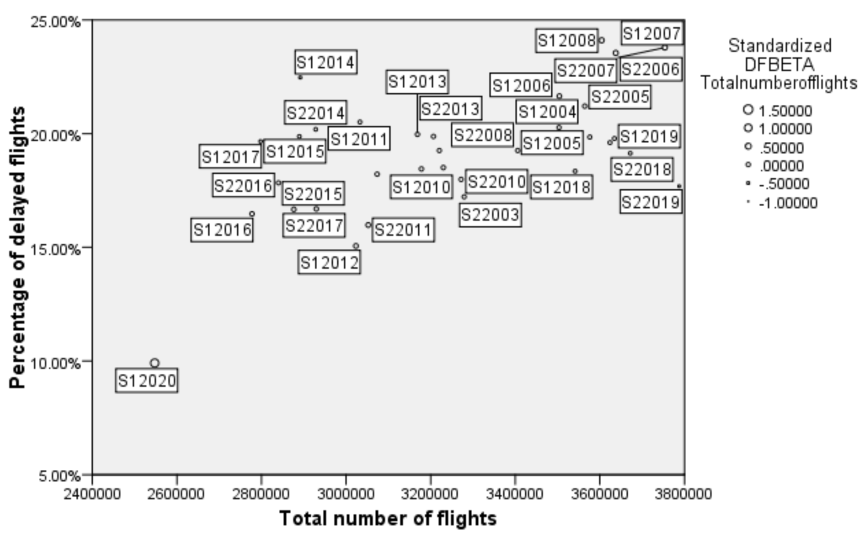

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Figure 24: Significance of the linear regression model concerning total number of U.S. domestic flights and percentage of delayed flights – Quarterly data

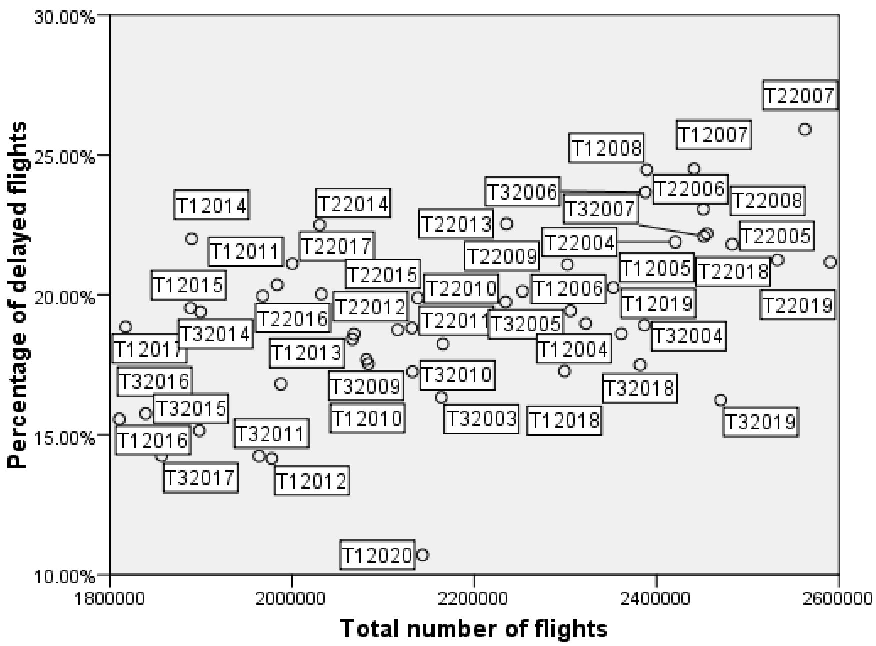
ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	122.508	1	122.508	18.158	.000[b]
	Residual	323.854	48	6.747		
	Total	446.362	49			

a. Dependent Variable: Percentage of delayed flights

b. Predictors: (Constant), Total number of flights

Figure 25: Percentage of Delayed Flights from 2007 to 2020 – Quarterly data



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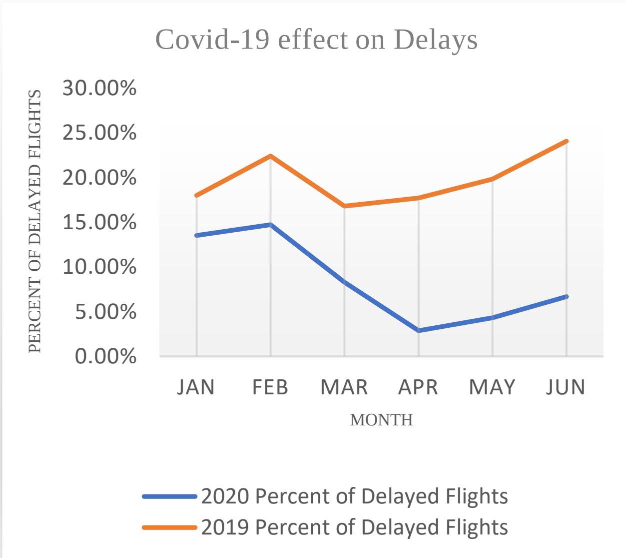

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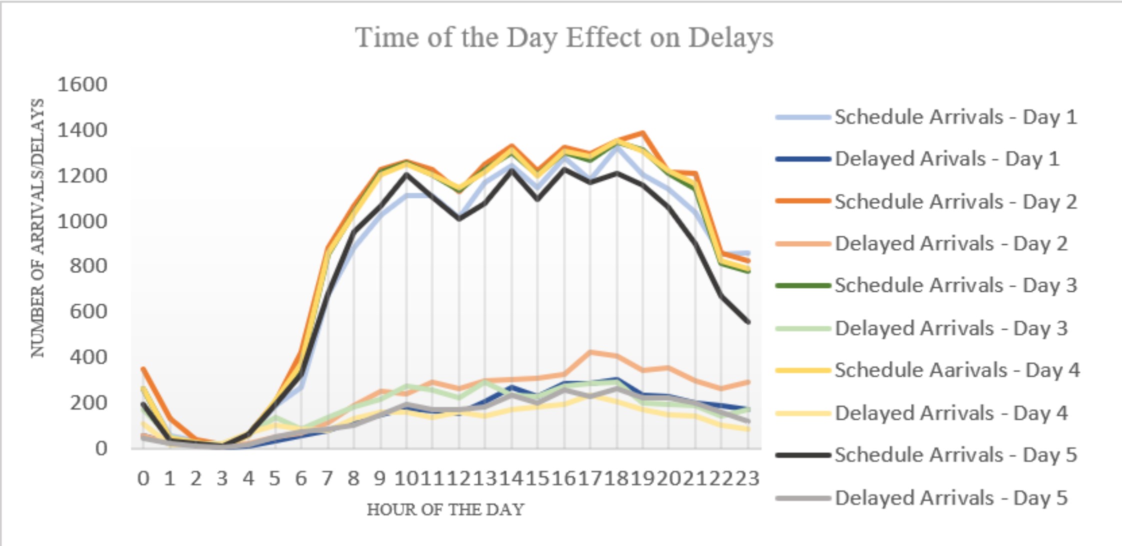
Figure 27: Difference in the percentage of delayed minutes of different causes of delay from 2019 to 2020

% of Total Delayed Minutes	Carrier	Weather	NAS	Security	Late aircraft arrival
2020	39.18%	5.95%	22.54%	0.15%	32.17%
2019	30.11%	5.91%	23.94%	0.16%	39.89%

Figure 28: Difference in the percentage of total operations delayed of different causes of delay from 2019 to 2020

% of Total Operations	Carrier	Weather	NAS	Security	Late aircraft arrival
2020	3.31%	0.37%	3.33%	0.02%	2.88%
2019	5.48%	0.70%	6.26%	0.04%	7.31%

Figure 29:



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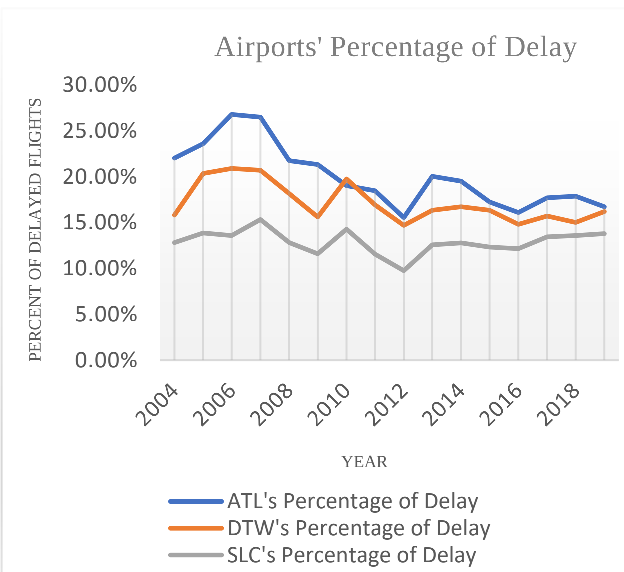

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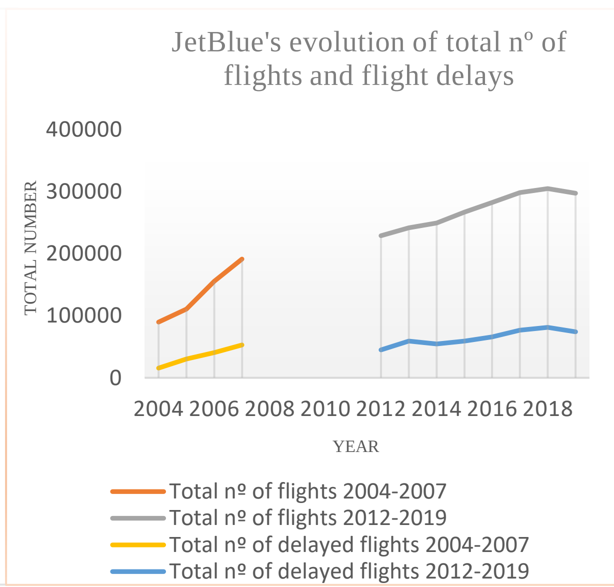

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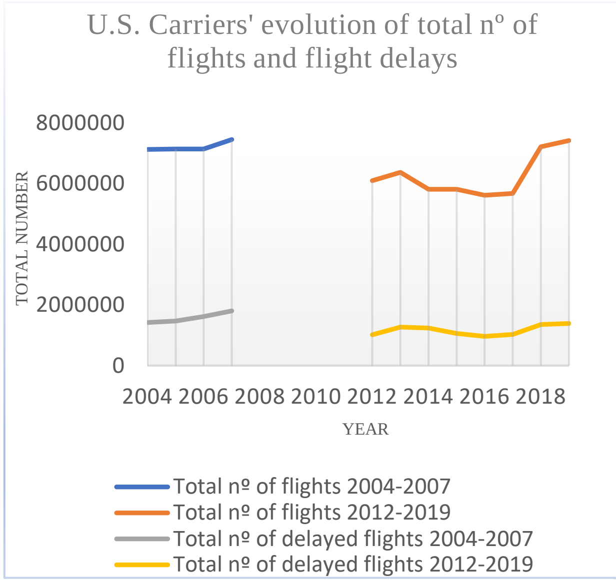

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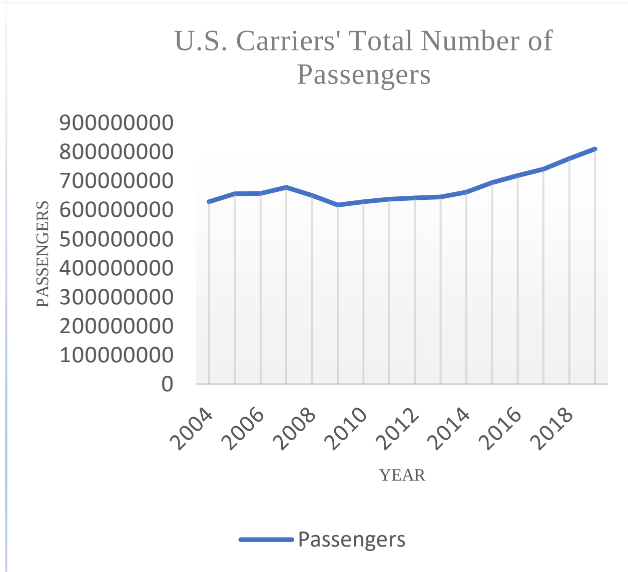

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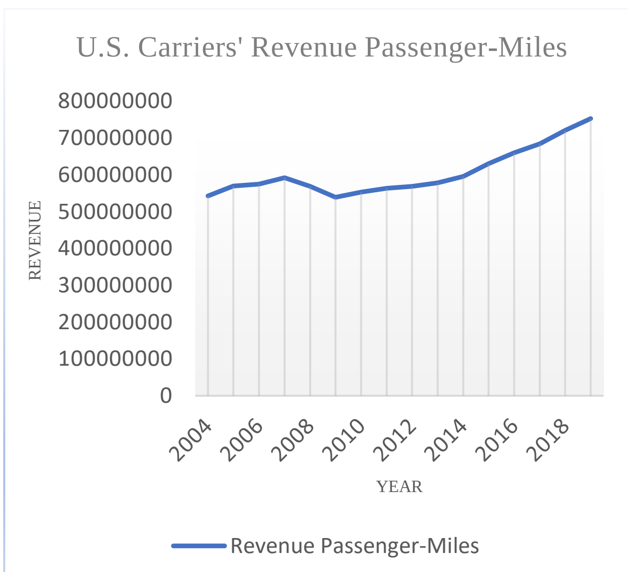

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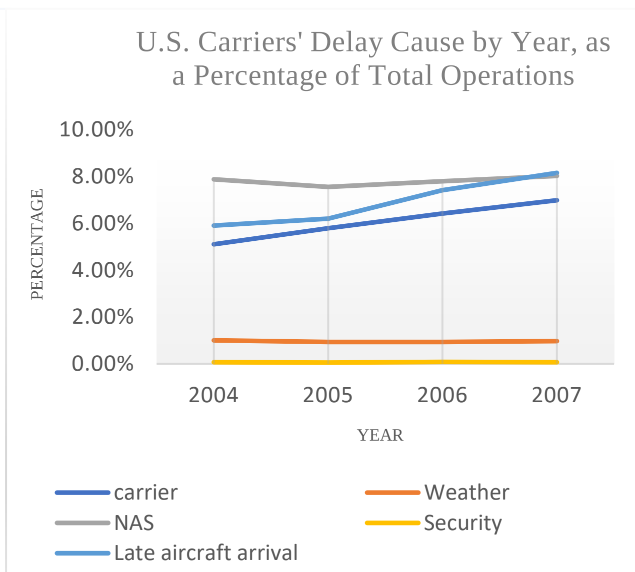
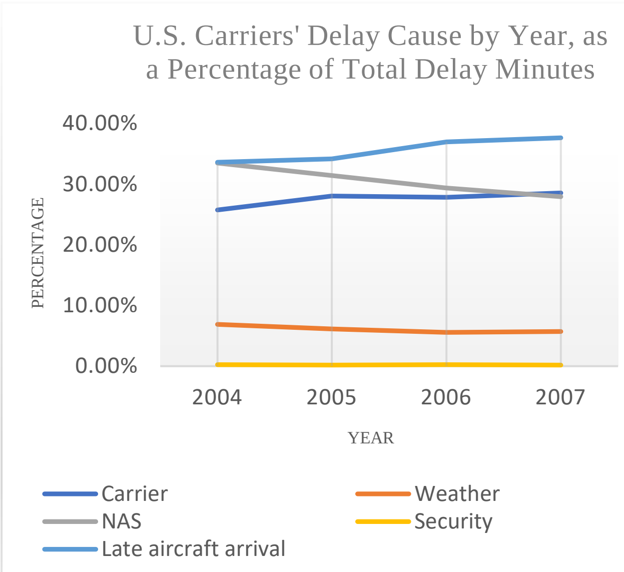


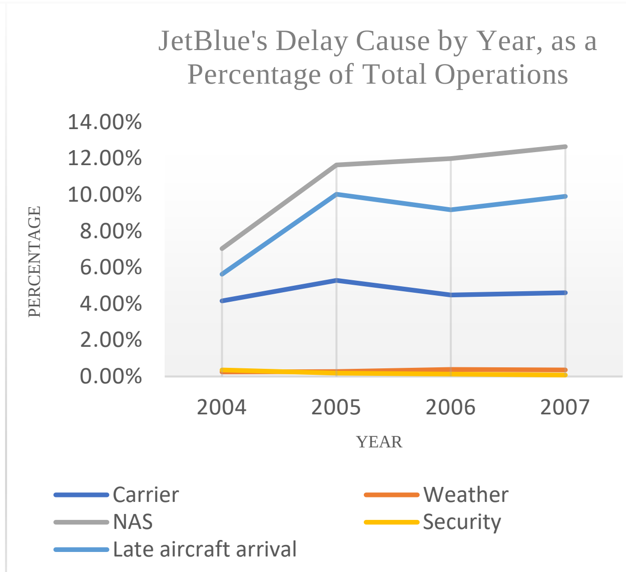
Source: Created by the author of the present WP with data extracted from BTS

Figure 36:



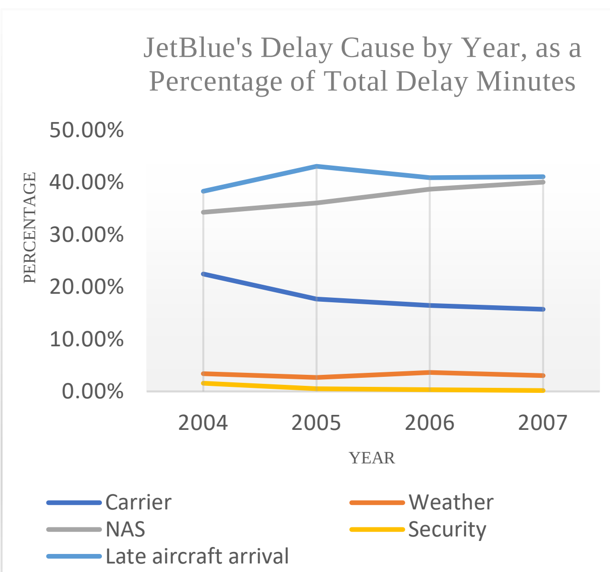
Source: Created by the author of the present WP with data extracted from BTS

Figure 37:



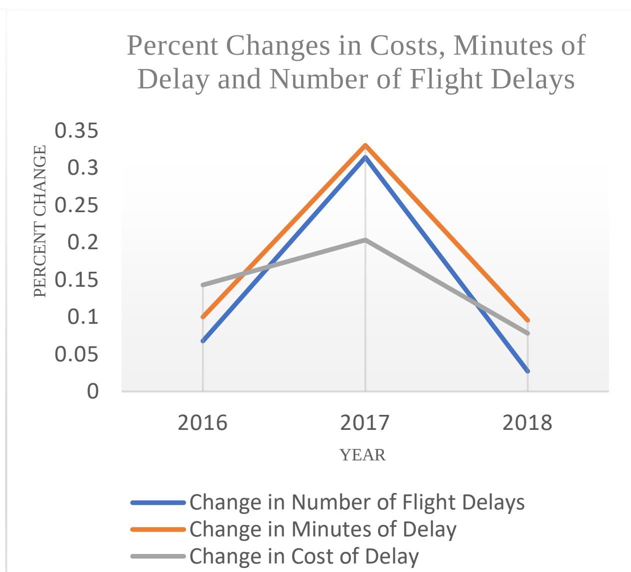
Source: Created by the author of the present WP with data extracted from BTS

Figure 38:



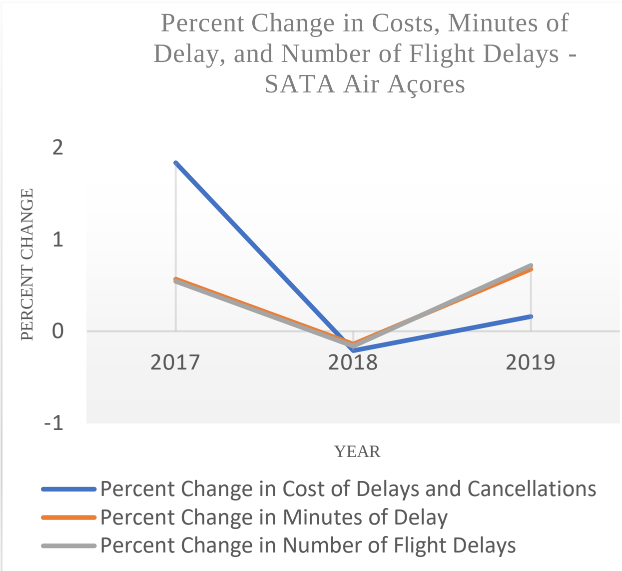
Source: Created by the author of the present WP with data extracted from SATA

Figure 39:



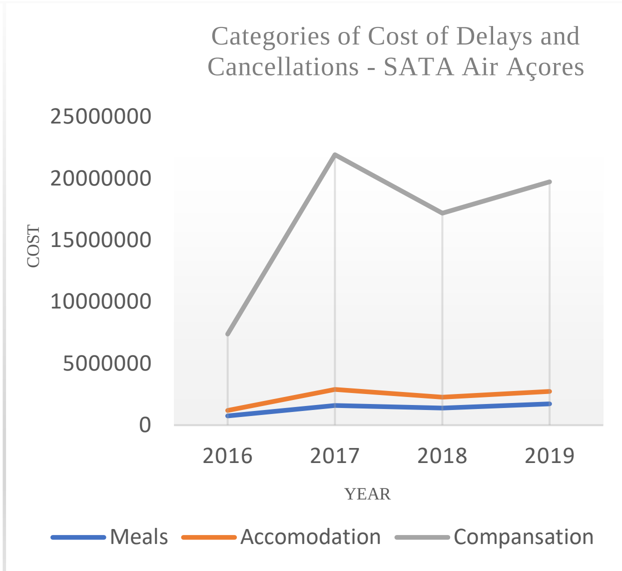
Source: Created by the author of the present WP with data extracted from SATA

Figure 40:



Source: Created by the author of the present WP with data extracted from SATA

Figure 41:



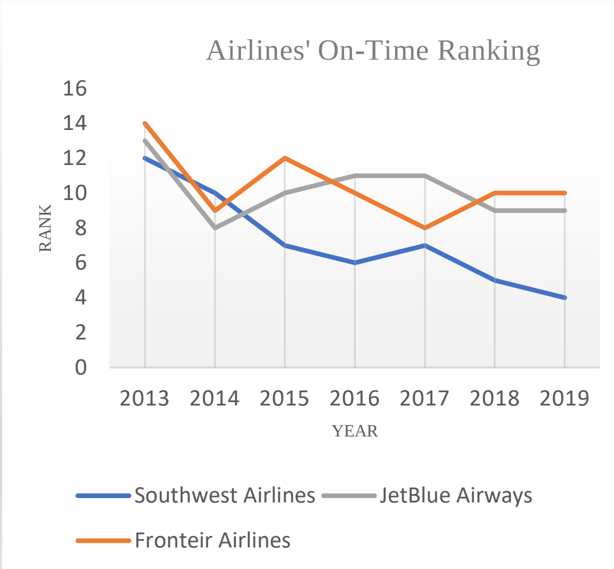
Source: Created by the author of the present WP with data extracted from SATA

Figure 42: Total cost of delay in the U.S. from 2016 to 2019

Total cost of Delay in the U.S. (dollars, billion)	2016	2017	2018	2019
Airlines	5.6	6.4	7.7	8.3
Passengers	13.3	14.8	16.4	18.1
Lost Demand	1.8	2.0	2.2	2.4
Indirect	3.0	3.4	3.9	4.2
Total	23.7	26.6	30.2	33.0

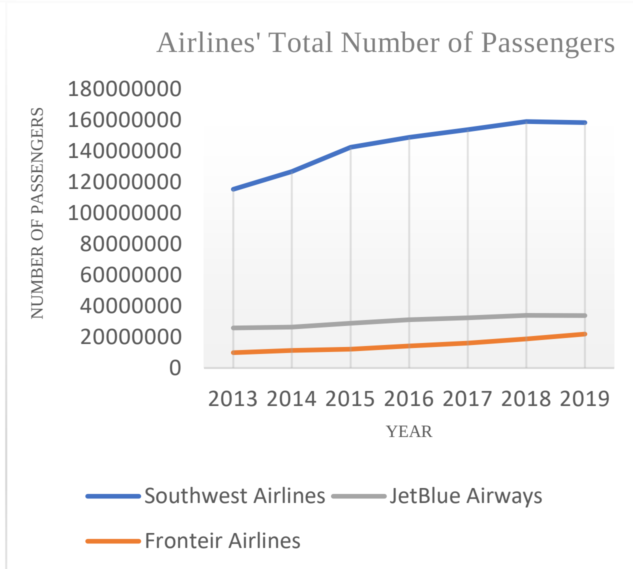
Reference: (FAA, 2019)

Figure 43:



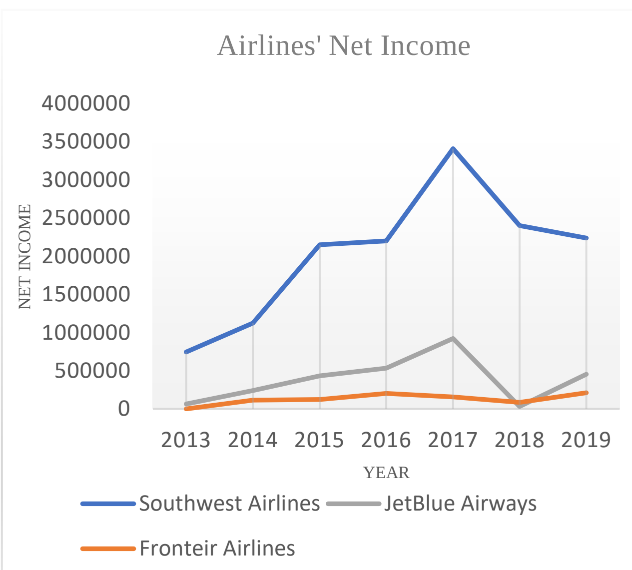
Source: Created by the author of the present WP with data extracted from BTS

Figure 44:



Source: Created by the author of the present WP with data extracted from BTS

Figure 45:



Source: Created by the author of the present WP with data extracted from BTS