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TOULOUSE-BLAGNAC DELAY MODEL

Synthesis of the Study

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Abstract :
This study has been conducted in partnership with the Direction de l'Aviation Civile-Sud
The study enabled to look, on a specific airport (Toulouse Blagnac), at the delay patterns. A thorough statistical analysis has been carried out and shows that:

1) most of the inbound flights with an arrival delay are not able to recover it on their subsequent flights
2) Delays in Toulouse, when extraordinary events do not happen, are quite predictable, depending on the city-pair, the arrival delay, number of passengers on board, etc…

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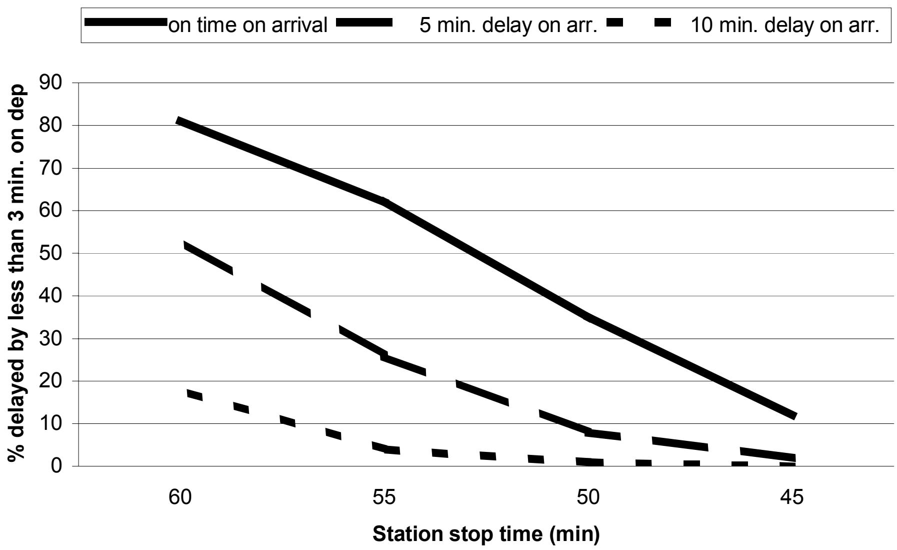
EXECUTIVE SUMMARY

The aim of this study, based on a partnership between Eurocontrol (Performance, Flow Management, Economics and Efficiency Business Area) and the local civil aviation authority (DAC Sud), was to assess the impact of arrival delays on departures (commonly referred to as the reactionary delay) and, further, to build a predictive model of the overall delay on departure from a single airport, Toulouse Blagnac.

Some 3000 turnarounds, concerning 18 different departure sites and destinations, and representing 42 traffic days (one week each month) throughout the first six-month of 2001 were analyzed. These city-pairs, served by 8 operators, represent roughly 50 % of the total traffic and 75 % of the regular passenger flights to and from Toulouse Blagnac.
There were approximately 50 % of regulated flights and 50 % of non-regulated flights in the initial sample. The latter were submitted to regressions on the departure delay against the explanatory variables in order to give a value to a numerical model predicting the strictly non-ATC part of departure delays.

The first result is that the delay on arrival is responsible for the major part of the overall delay on departure for station stop times of less than 60 minutes. Indeed, a flight delayed 10 minutes on arrival is on average delayed by 5 to 6 minutes on departure. This basic relationship is linear, which reflects the “mechanical” effect of delays : minutes “missing” on arrival (because the plane was late) are still “missing” on departure in order to achieve the scheduled time. Furthermore when delays on arrival are long with respect to the station stop-over time, a quadratic effect is added to the delay on departure.
In addition, a quadratic effect of the delay on arrival – whatever the station stop-over time – is sensitive for long delays on arrival with regards to the station stop-over time.
Another important result is that departure delay is very sensitive to station stop-over time. On average, it increases by 2 minutes when station stop-over time is reduced by 5 minutes (in the 60-30 minute interval). For a very short station stop-over time (25 to 30 minutes) the increase is by 4 minutes. For different delays on arrival, the figure here below shows the probability of a flight to achieve the scheduled hour (flight delayed by less than 3 minutes on departure) as a function of the station stop time:



From this figure it can be observed that the probability to achieve the scheduled hour increases as the station stop time increases. This trend is more sensitive for small delays on arrival (with a 10 minute delay on arrival, most of the flights are delayed on departure even for station stop-over time of 60 minutes).

The relative passenger load of the aircraft obviously plays a part in the departure delay. This load affects in particular check-in operations since the indicator that was processed included the standard rate at check-in for each airline in the sample. Its effect is greater as the station stop-over time decreases. On average, an increase by 10 passengers generates an increase of the departure delay by 1 minute. Terminal congestion (the number of passengers in the terminal) adds a small positive component to the average delay on departure.

On the other hand, there is a significant effect on delays of a moderate reduction in runway capacity (e.g. in the case of annual repairs). Reducing the ATC/airfield device capacity by 30 % (e.g. when one of the two runways is closed without any restriction on taxiways [1]) generates an increase in the departure delay by 4 minutes.

The statistical model built within the project gave satisfactory results:

Although the arrival delay IS THE MAJOR CONTRIBUTOR TO the departure delay, taking station stop time and local factors into account actually improves the correlation. Moreover, it gives evidence that, if all flights on arrival were on time, the average delay on departure would still be 3.1 minutes as against A CURRENT delay by 6.5 minutes for non-regulated flights.

For regulated flights, the ATC-delay was considered to be an input and the overall delay was expected to stand between the lower edge of the predicted non-ATC delay and the highest value between ATC-delay and predicted non-ATC delay (this illustrates the fact that ATC delays can sometimes “cover” non ATC delays). The model prediction shows ATC-delay is not the most constraining factor of the overall delay for 35 to 50 % regulated flights, depending on the station stop time.

Since the predictive value of the model has proved to be relatively sound, future applications may be considered in long-term or short term prevision (increase in traffic, scheduled events, flight operations). Extension of this work to other airports and checking the relationship between the delay on departure from the opposite airport and the delay on arrival (flight duration) will provide the keys to complex - but realistic – models for reactionary delays.

[1] For information the capacity in LVP is reduced by 40 to 60 %

1. INTRODUCTION

1.1 Project Objective

1.1.1 Looking for a model explaining delays development

We intend to analyse « all causes delays » (TCC), according to the definition : difference between scheduled time and ABT (actual block time). In fact, TCC delay comes as close as possible to the perception of delays by passengers. Stronger correlation to the perception of delays by passengers (« gate to gate ») requires further investigations and devices i.e. surveys in order to collect data which are still not routinely recorded.

1.1.2 A model focusing on traffic level

We focus on traffic effects throughout a quantitative approach, i.e. search for correlations between the length of delays and aircraft or passenger flows. We are not so concerned about processing recorded causes for labelled delays, the latter usually being privileged in studies about delays in air transport. The reason is that we are more interested in measuring the aptitude of operators to cope with effects of primary causes (e.g. a passenger missing by the end of check-in time, low visibility on airfield) rather than dealing exhaustively with primary causes.

Our aim is, more precisely, to know how far the aptitude of operators to cope with effects of primary causes is sensitive to the intensity of flows (aircraft and passengers). In fact, this approach is very close to the concern of air transport operators – particularly ATM and airport operators – in terms of capacity. It is noticeable that – in words – capacity, traffic increase and delays are frequently associated ([2]).

1.1.3 Toulouse Blagnac airport as a «key-in»

Analysing a complex system usually requires proceeding from a « point of view », using a « key in ». A « point of view » is all the more necessary in the case of punctuality in air transport since the making-of delays process is potentially closed, with major feedback effects. Delays are likely to spread throughout the system, because of flight turnarounds. Spreading of delays may affect an airline, an airport or even all of the flights of an operator at the same time.

The « airline » object, which has been chosen by French COMUTA for several studies on punctuality ([3]), is a possible « point of view ». We have chosen « a single airport point of view » (i.e. Toulouse Blagnac airport) because of its both global and local interest.

The local point of view is related to concerns of ATC, airport management, airlines and others (in Toulouse, the aircraft industry for instance) : What local factors are mainly implicated in the increase of delays ? Are delays sensitive to local ATC configurations ? Are they sensitive to the volume of local traffic ? Many questions are related to the matter of local capacity.

([2]) See for instance EUROCONTROL/EATMP web site : « Air traffic continuously increasing – Delays under control ? » (W. Philipp)
([3]) Since 1999, 4 airlines have been studied : Orly-Nice, Orly-Toulouse, Roissy-Nantes and Orly-Fort de France.

On the other hand, « a single airport point of view » is consistent with a global point of view through turnaround process.

1.2 Aim of the document

The present document is the final deliverable of the project described here below. It is the synthesis of the study summarizing the two previous deliverables [RD. 2] & [RD. 3] and describing the delays model on Toulouse Blagnac airport.

After introduction of the project objectives, the Section 2 aims at describing the method and material used for the present study. It first presents the canonical form of the model to be built both for delays on arrival and departure. It then characterizes the data source used for such a model elaboration. In addition, this section presents the chosen samples used for the data analysis.

The Section 3 presents the exploratory data analysis that has been carried out on available database (ATS/Airport database, en-route traffic and regulations, delay on departure from the opposite airport, passenger flows and processing, meteorological events, local ATC configuration, and airfield disruptions) .

Then, an additional data analysis (Section 4 : Correlations) has enabled some correlations or influence between factors (delay on arrival, airline, station stop time) to be highlighted.

Section 5 presents the models derived from the results previously presented (need of segmentation of the sample, correlations, etc.). The performances of these models (average deviation of the predicted delay, standard deviation, etc.) are given in Section 6.

Finally, Section 7 gives an overview of the model, the way it has been processed and a discussion on results and applications is proposed.

Section 8 is a synthesis of the study.

1.3 References document

[RD. 1] EUROCONTROL/EATMP web site : « Air traffic continuously increasing – Delays under control ? » - W. Philipp

[RD. 2] "Toulouse-Blagnac Delay Model : Data Source Identification and Characterization" – CS Systemes d'information – CSSI/129-01/MDB/IM/30073 – 18/2/2002.

[RD. 3] "Toulouse-Blagnac Delay Model : Statistical Model Definition" – CS Systemes d'information – CSSI/129-01/MDB/IM/30074 – 18/2/2002.

2. Material and Method

2.1 Canonical form of the model

Let DL(i) the dependent variable, TCC delay for the movement (i). Independent variables are either quantitative or qualitative. All variables, particularly qualitative variables, may be synthetic. One option is to depict the state of environment (weather, en-route traffic for instance) by the mean of structural or functional typologies which give a basis for synthetic variables.

DL (i) in minutes = f (var_1, var_2, …, var_n)

In fact, we are planning to design two numerical functions, one for arrivals, the other for departures.

a) Delays on arrival :

Let DLA(i), delay on arrival of the movement (i).

DLA(i) = F(DLD (i) ,
Processing en-route traffic,
Processing (local) traffic on arrival)

DLD(i) is the delay for the flight (i) on departure from the opposite airport.

In fact, processing en-route traffic is not our concern for flights on arrival. It is a component of DLD(i) which should be weighed in a similar model applied to the airport of departure. Thus, the form is simpler :

DLA(i) = F(DLD (i) ,
Processing (local) traffic on arrival)

Processing (local) traffic on arrival is analyzed as follows :

- Structure and volume of local traffic (aircrafts) ;
- Airfield disruptions ;
- Meteorological events (storm, LVP, snow on airfield, etc.) ;
- configuration of local ATC.

b) Delays on departure :

Let DLD(j), delay on departure of the movement (j).

DLD(j) = F(DLA (j) ,
Processing (local) traffic on departure,
Allocating a slot)

DLA(j) is the delay of the movement (j) on arrival (turnaround).

Processing (local) traffic on departure is analyzed as follows :

- Processing passengers and baggage ;
- Structure and volume of local traffic (aircraft and passengers) ;
- Airfield disruptions ;
- Meteorological events (storm, LVP, snow on airfield, etc.) ;
- configuration of local ATC.

The slot allocation process includes regulation aspects, thus processing en-route traffic, but it is not our major concern. We wish to focus on that process when a given slot time cannot be achieved for any reason independent of ATC regulations. In other words : extra delay caused by the allocation of a new slot when an operator is subject to a primary cause of delay.

In fact, the model for delays on arrival has not been developed because it is expected to be much simpler and may well be implemented later. On the other hand, cases with a declared change in block time on departure were not numerous enough to be processed.

2.2 Source of Information : Origin and Object

2.2.1 Analysing ATS/Airport Database

ATS/Airport database is a file in which all movements performed on Toulouse Blagnac airport are recorded This database was already available and has been processed in order to :

- Identify airlines stable throughout the studied period ;
- Identify and weigh airliner / assistance operator configurations ;
- Assess the average delay per configuration ;
- Set the relation $DL_D = f(DL_A)$ for each configuration.

Our aim is to build factorial plans based on the observed variability of practices and environmental parameters. This is very unlikely regarding the process of flights, passengers and baggage by private operators. In fact, links between « airlines » and « assistance operators » are not randomly distributed but the result of special agreements.

On the one hand, our point of view focuses on « airlines », « airport » and « ATC » as sub-systems, their interactions and sensitivity to variations in traffic level. Detailed analysis of internal dysfunctions, regarding airlines and airport operations, is not our concern.

On the other hand, we wish to produce explanatory keys of the average result of an airport in terms of punctuality. From this point of view, the individual weight of an operator in the local traffic and its « average performance » in terms of punctuality is a structural component of the average delay for the airport throughout a given period.

Another application of ATS/Airport database is to give indications of the flow (traffic, passengers) in order to assess correlations between delays and flows. Each movement in the database bearing a date and time, it is possible to compute the number of movements between e.g. t-15 and t+15 min. Moreover, it may be relevant to take into account the structure of the instant traffic including all types of traffic likely to interfere with commercial flights, especially VFR and local flights (aircraft industry trials).

2.2.2 Processing en-route traffic and slot allocation

En-route traffic is analysed from two points of view :

- Routing : i.e. average profile of flights in the sample, variability of routes and FL, as information.
- Delays : for the flights in the sample, extraction of national flight plans and CFMU archives have been requested in order to identify regulations. A major concern is to crosscheck the relevance and accuracy of our data regarding published statistics on ATC-delay. Another major concern is to assess the consequences of the allocation of a new slot when a given slot time cannot be achieved for any reason independent of ATC regulations. In any case, ***the major concern is to identify flights submitted to a regulation (regulated flights)***.

2.2.3 Collecting information from the airport management and local representation of airlines

The aim is to identify structural and functional configurations for passengers and baggage process on departure : allocation of the terminal infrastructure and equipment, processing, in order to roughly qualify and quantify the variability of terminal means operating for the benefit of each flight. Means are qualified or quantified as long as they may affect punctuality, in order to give explanatory keys to correlations, e.g. between delays and passenger flow.

2.2.4 Meteorological events

A file of meteorological events likely to affect movements on approach or on departure has been extracted from the Meteorological survey archives. The aim is to identify situations like LVP, snow on runways or storms in the approach segments, which may have a drastic effect on local capacity.

2.2.5 Airfield disruptions

Local archives (paper) have been collected and processed. A file has been drawn, coding events like e.g. « closure runway 2 ».

2.3 Sample design and General Features

2.3.1 Date/Time

Initially, we wished to control the “year effect” by taking into account flights over several years, e.g. 1997 to 2001. This period was restricted to :

- first six months of 2000 ;
- first six months of 2001.

On the one hand, restoration of stored data from Flight plan archives would have been too long with regard to the short-term end of the study. We had to restrict our request to roughly 40 days for data before 01/01/2001. Wishing to control the within-year effect (i.e. week effect) and day-of-week effect (thus, batches of 7 days), we decided to request extraction from stored data for one whole week per month from January to June (6 x 7, i.e. 42 days). The last six-month period of 2001 had to be discarded with regard to the tragic events in the U.S. and the consequences on air traffic. Moreover, new en-route procedures (ARN-V3) were effective during the first six-month period of 1999, with temporary negative consequences on delays. Thus, it was not relevant to take 1999 into account.

For each month – from January to June 2000 on the one hand, and from January to June 2001 on the other hand, we sampled one week with regard to special events recorded by French DGAC/DNA/SCTA and Toulouse airport operator (CCIT) :

- we discarded weeks with strikes (DGAC, airliners, airport operations, restricted to Toulouse for the latter) ;
- weeks overlapping over two months ;
- weeks with air navigation systems failures (in fact, this criterion was applied to 2001 and, only if possible, to 2000 ; in any case, weeks with major failures involving significant dysfunction were discarded) ;
- weeks with legal holidays.

In other words, weeks with days affected by major events involving significant dysfunction were discarded, with the noticeable exception of meteorological events.

In conclusion, the following weeks were sampled :

Month	Week number	2000	2001
January	3	From Mon-17 to Sun-23	From Mon-15 to Sun-21
February	8	From Mon-21 to Sun-27	From Mon-19 to Sun-25
March	11	From Mon-13 to Sun-19	From Mon-12 to Sun-18
April	16	From Mon-17 to Sun-23	From Mon-16 to Sun-22
May	20	From Mon-15 to Sun-21	From Mon-14 to Sun-20
June	25	From Mon-19 to Sun-25	From Mon-18 to Sun-24

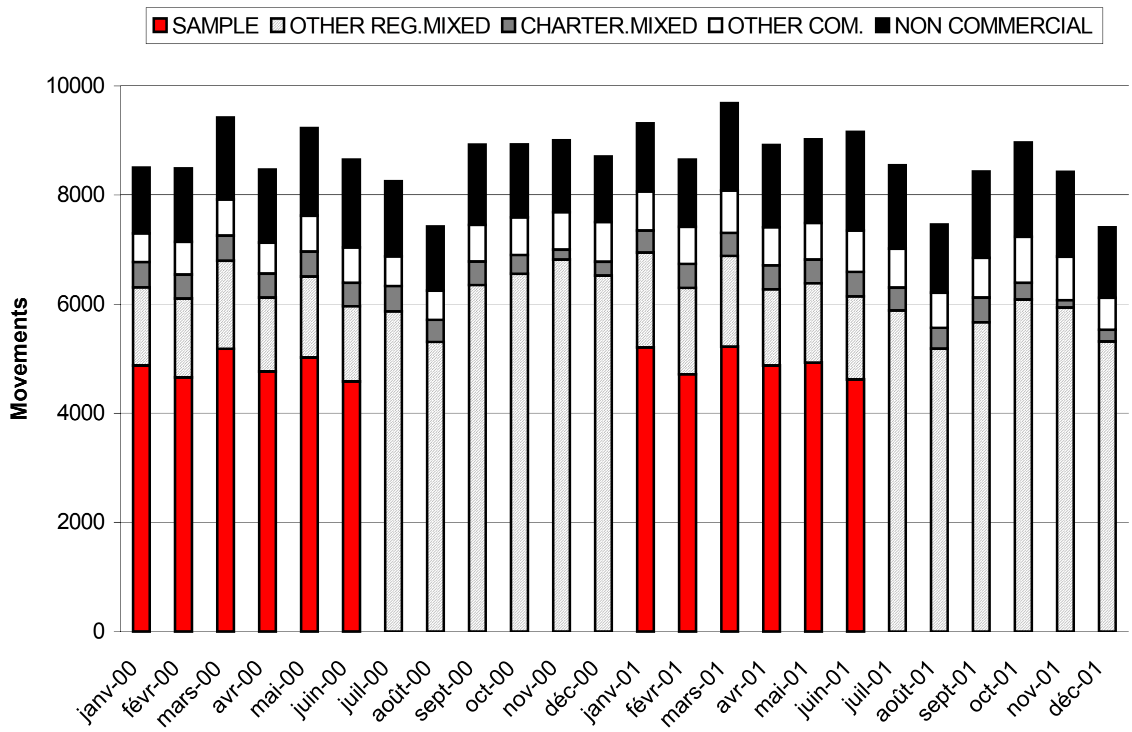
In fact, data for the year 2000 were not available soon enough to be processed. However, they are now available and might be used for further validation of the model.

2.3.2 Operators and airlines criteria

Each airline in the sample had to be stable throughout the period and display a sufficient number of turnarounds (i.e. 3 turnarounds per day on average throughout the period). Thus, we discarded charter flights and focused on regular flights taking passengers fulfilling the latter requirement. The initial sample is thus as follows :

Operator	IATA code	Departure / Destination
AIR France	AFR	EGLL London Heathrow
		LFLL Lyon St Exupéry
		LFMN Nice Cote d'Azur
		LFPG Roissy Charles de Gaulle
		LFPO Paris Orly
		LFQQ Lille Lesquin
		LFRN Rennes St Jacques
BRITISH AIRWAYS	BAW	EGKK London Gattwick
CROSSAIR	CRX	LSZM Bale Mulhouse
LUFTHANSA	DLH	EDDF Frankfurt Main
		EDDM Munchen
KLM	KLM	EHAM Amsterdam Schiphol
AIR LIBERTE	LIB	LFJL Metz Nancy Lorraine
		LFMK Carcassonne Salvaza
		LFPO Paris Orly
		LFRS Nantes Atlantique
AIR LITTORAL	LIT	LFMN Nice Cote d'Azur
SABENA	SAB	EBBR Brussels National

Those 18 airlines from 8 operators represent roughly 50 % of the total traffic, 65 % among the commercial flights and 75 % of the regular flights taking passengers on Toulouse Blagnac airport as shown on the figure here below.



2.3.3 General features of local traffic throughout the period

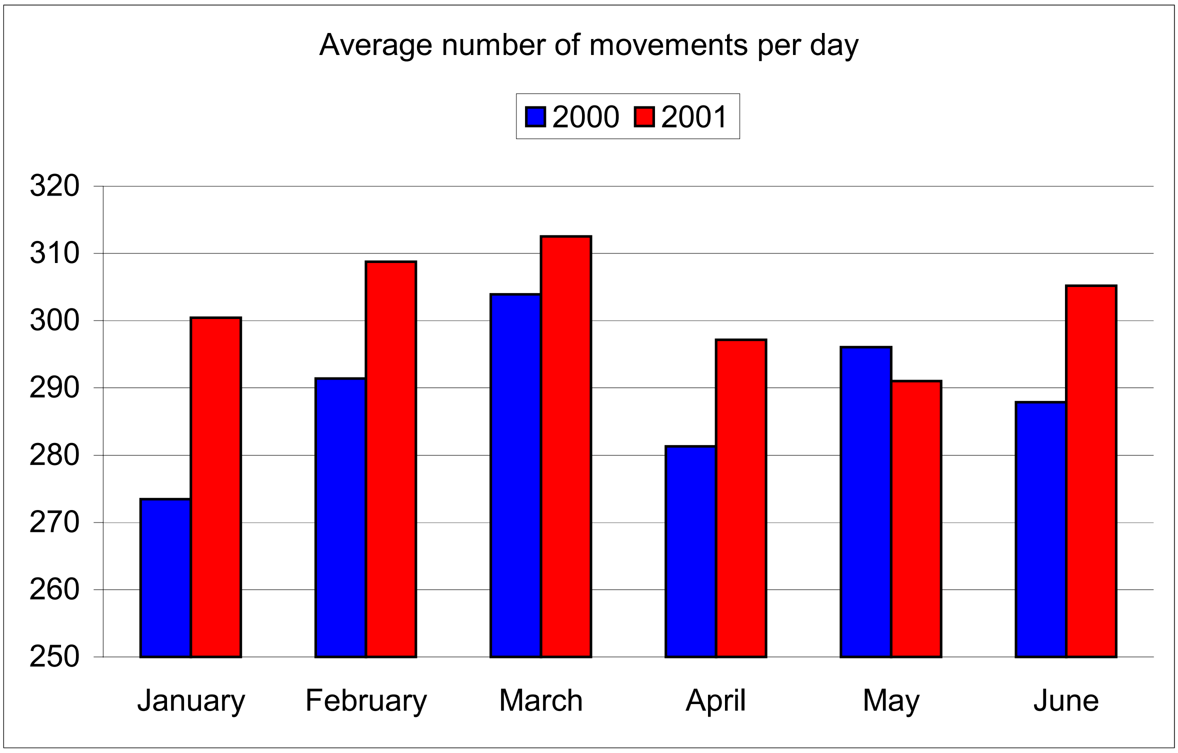
Toulouse Blagnac database included up to 103,513 records depicting some 107,341 movements for months January to June 2000 and 2001.

Month	Year				% 2001 / 2000 (Mov./Day)
	2000		2001		
	Total	Mov./Day	Total	Mov./Day	
January	8477	273	9313	300	+ 10%
February	8451	291	8645	309	+ 6%
March	9422	304	9688	313	+ 3%
April	8439	281	8915	297	+ 6%
May	9178	296	9021	291	- 2%
June	8636	288	9156	305	+ 6%
Total	52603	289	54738	302	+ 5%

Aircraft traffic has increased by 5 % in 2001 compared to 2000. Traffic usually increases from January to March (with an absolute peak in March for the first six months). Next, it is usually higher in May than in April or June (see 2000). This is related to the low holiday-related proportion (and, conversely, high job-related proportion) in Toulouse Blagnac traffic.

When considering the intensity of traffic (average number of movements per day, see below), these relative proportions of job and holiday trips also explain :

- The strong increase of Jan-01 on Jan-00 ;
- The minimum traffic on May-01 vs May-00.



As previously indicated, sample of 18 airlines from 8 operators represent roughly 50 % of the total traffic, 65 % among the commercial flights and 75 % of the regular flights taking passengers at Toulouse Blagnac airport.

Out of 103,513 records (total traffic), with reference to the "airlines" criteria, some 58,500 records were initially selected. Restriction to the 84 days in the sample resulted in selecting 13,691 records : 6,849 arrivals and 6,842 departures.

Further restriction to 2001 data resulted in a file of 3,146 turnarounds (arrival + departure).

2.3.4 Overall delays : statistical parameters

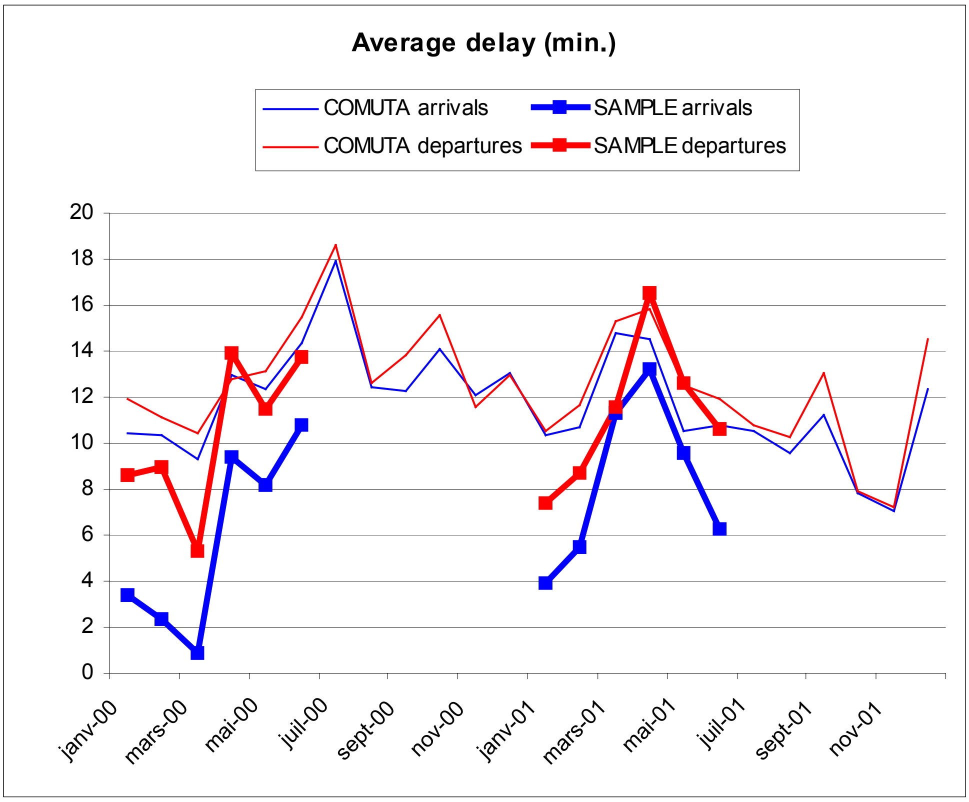
The first result that can be outlined is the overall delays in the whole sample. The table here below gives the statistical parameters of the delay for each airline:

	Arrival			Departure		
Airline	Number	Mean	SD	Number	Mean	SD
AFREGLL	235	5.1	24.6	236	11.2	22.2
AFRLFLL	357	5.7	18.3	357	6.4	16.5
AFRLFMN	103	-7.7	16.0	103	7.9	16.6
AFRLFPG	565	16.1	21.9	562	13.3	18.6
AFRLFPO	1822	7.5	17.0	1826	9.5	14.8
AFRLFQQ	225	6.1	22.8	221	11.8	22.4
AFRLFRN	185	3.2	15.6	184	5.6	9.2
BAWEGKK	250	4.7	29.2	249	10.5	22.9
CRXLSZM	220	15.0	21.1	219	19.9	16.7
DLHEDDF	247	-6.6	17.1	248	12.6	23.5
DLHEDDM	167	4.3	19.4	166	10.0	10.6
KLMEHAM	245	7.2	25.3	243	14.2	24.8
LIBLFJL	116	-5.1	14.5	116	9.3	10.3
LIBLFMK	176	0.1	11.3	178	8.7	17.9
LIBLFPO	1078	8.4	22.6	1079	12.1	19.1
LIBLFRS	219	3.6	17.7	204	11.5	13.5
LITLFMN	389	10.2	21.9	388	7.6	14.4
SABEBBR	224	10.6	19.0	223	13.0	14.9
All	**6823**	**7.1**		**6802**	**10.8**	

In the whole sample, the delay on arrival is on average 7.1 mn. On the other hand, the delay on departure is on average 10.8 mn (+ 3 mn).

One important point is to check the relevance of monitoring boards currently in use. At Toulouse Blagnac, COMUTA board is applied, based on average delay (arrival and departure) for all types of commercial flights, including charters.

The Figure here below shows average delay per month issued by COMUTA compared to values in our sample.



A previous study (Bertocchio, 2000) showed that the average delay for charters is close to the average delay for regular flights although individual delays are much more heterogeneous. Thus, presence of charters in the COMUTA sample might not be sufficient to explain the difference in means between the two sources, delays in our sample being less or equal to those of COMUTA. In fact, the main reason for that difference is that, in our study, negative delays (aircraft ahead of time) are taken into account and not computed as zero.

3. Exploratory data Analysis and pre-processing input files

The first step consists in exploratory data analysis in conjunction with pre-processing input files, including :

- computing additional variables (e.g. station stop-over time, etc.) ;
- vertical matching of files, e.g. matching the file derived from ATS/airport database with data extracted from FPL file ;
- horizontal segmentation, e.g. breaking the reference file in two, one for regulated flights, the other for non-regulated flights.

The latter operation is of importance for further analysis when you have two populations (or more) which are not submitted to the same laws.

3.1 ATS/Airport database

3.1.1 Turnaround

Turnaround identifier is linked to the same plane on arrival (or departure) even if the latter is a non-commercial flight. In this case, there is no scheduled time (thus no delay to be computed) but data ,for example, actual block time or departure / destination aerodrome are nevertheless available.

a) Matching arrival and departure segments in the reference file :

Airline	Number (1)	Number (2)	% (2)	Number (3)	% (3)
AFREGLL	154	146	95%	146	95%
AFRLFLL	283	281	99%	233	82%
AFRLFMN	93	57	61%	39	***42%***
AFRLFPG	409	409	100%	371	91%
AFRLFPO	1523	1521	100%	1469	96%
AFRLFQQ	221	218	99%	216	98%
AFRLFRN	184	155	84%	149	81%
BAWEGKK	168	167	99%	88	***52%***
CRXLSZM	219	219	100%	219	100%
DLHEDDF	165	165	100%	165	100%
DLHEDDM	125	125	100%	125	100%
KLMEHAM	163	163	100%	163	100%
LIBLFJL	116	114	98%	12	***10%***
LIBLFMK	174	170	98%	5	***3%***
LIBLFPO	870	851	98%	714	82%
LIBLFRS	203	93	46%	90	***44%***
LITLFMN	305	305	100%	304	100%
SABEBBR	140	140	100%	140	100%

Number (1) is the number of movements on departure in the sample (airline and day) linked to an arrival on the same day. Number and % (2) are related to movements on departure which are, in addition, linked to an arrival in the sample. Further analysis shows that the difference is due to aircraft which, on arrival segment, are operated by an extra airline and/or have not departed from one of the 16 airports above. Share of non-commercial and/or non- regular and/or non- mixed is never more than 2 %. Number and % (3) are related to movements on departure which are, in addition, linked to an arrival performed on the same airline.

The latter case is the most frequent, generally more than 80 %. There are some noticeable exceptions :

- Only 42 % of the departure segments for AFR/LFMN are linked to an arrival segment from AFR/LFMN and 61 % are linked to an arrival segment not in the sample although performed on the same day. Some 20 % of the departure AFR/LFMN are linked to an AFR/LFLL arrival and some 20 % more are linked to an arrival performed by the same operator from an extra airport (LEMD).
- Only 52 % of the departure segments for BAW/EGKK are linked to an arrival segment from BAW/EGKK. Almost all of the other departure segments are linked to a LIB/LFPO arrival.
- Only 44 % of the departure segments for LIB/LFRS are linked to an arrival segment from LIB/LFRS. Almost all of the other departure segments are linked to an arrival performed by the same operator from an extra airport (LFML).
- Only 3 % of the departure segments for LIB/LFMK are linked to an arrival segment from LIB/LFMK. In fact, 60 % of the departure segments are associated to an arrival segment from LFJL and 35 % to an arrival segment from LFPO.
- Only 10 % of the departure segments for LIB/LFJL are linked to an arrival segment from LIB/LFJL. Close to 90 % of the departure segments are associated to an arrival segment from LFMK.

This first step analysis suggests the need of defining “types” of turnarounds. Nominal turnarounds are likely to be traffic-dependent while exceptional turnarounds are very likely to be not the cause, but the result of delay !

b) Defining types of turnaround

Flight codes on departures have been stored – for both regulated and non-regulated flights in the same file – with reference to the airline and the total number of records in the sample for each flight code (4).

We had to consider separately night stop flights i.e. 185 for non-regulated flights and 437 for regulated flights. They will later be integrated in order to analyse effects of traffic, capacity, terminal process, etc. but we assume it is not necessary to take turnaround into account.

Turnarounds have been classified into 3 types :

(4) One flight had to be removed : AFR6151 on Sunday 2001-June-24 was flying to LFPG while it is usually scheduled to LFPO.

- **STD** are standard turnarounds. We usually have a single flight code on arrival segment in correspondence with any flight code on departure segment. For instance, AFR7851, on departure to LFLL, is always linked to an AFR7850 on arrival (31 records in our sample). However, in order to decide if a special arrival segment (e.g. AFR6108) was ***a*** standard turnaround for a special departure segment (e.g. AFR7849), we had in some cases to take into account variability depending on the season and/or the day of the week (see ***Special cases***, appendix). For instance, AFR7840, AFR6108 and AFR6118 are all standard turnarounds (arrival segments) for departure AFR7849.

- **OTH** are all other commercial, regular flights taking passengers, which cannot be considered to be standard. According to the method above, not only are they exceptional as an arrival segment for the flight on departure they are linked to, but also it is not possible to find any regularity (for instance, every Sunday). These flights on arrival segment play, to some extent, the role of a “wild card”.

- **SET** are setting up of an empty aircraft.

We have 117 STD, 14 OTH and 4 SET. Distribution of types across airlines is in table below.

Airline	Data	Type of turnaround			Total
		OTH	SET	STD	
AFR	Number	16	3	1210	1229
	%	1.30%	0.24%	98.45%	100.00%
BAW	Number			84	84
	%	0.00%	0.00%	100.00%	100.00%
CRX	Number			75	75
	%	0.00%	0.00%	100.00%	100.00%
DLH	Number			165	165
	%	0.00%	0.00%	100.00%	100.00%
KLM	Number			82	82
	%	0.00%	0.00%	100.00%	100.00%
LIB	Number	5	1	660	666
	%	0.75%	0.15%	99.10%	100.00%
LIT	Number	1		145	146
	%	0.68%	0.00%	99.32%	100.00%
SAB	Number			69	69
	%	0.00%	0.00%	100.00%	100.00%
Total / type (number)		22	4	2490	2516
Total / type (%)		0.87%	0.16%	98.97%	100.00%

We underline two noticeable results :

Regarding the number of movements, the proportion of non-standard turnarounds is less than we expected. In any case, it does not exceed 2 %. However, we have twice reduced the initial sample, (1) in year 2001 only and (2) by discarding flights with missing FPL data. As a result, we do not observe, in that restricted sample, cases like departures following a charter flight, a relief flight or a return-to-parking on arrival segment, which exist.
All of the airlines do not have equal opportunities to play non-standard turnarounds as “wild cards”. In fact, it depends very much on the density of routes to/from Toulouse Blagnac.

Thus, it is not surprising that AFR and LIB are responsible for almost all of the non-standard turnarounds.

3.1.2 Delay IATA codes

Until recently, delay IATA codes were not thoroughly completed when necessary in the ATS/airport database (overall delay on departure over 15 minutes). Amongst some 80,000 commercial, regular, mixed movements on departure, 12,020 IATA codes were recorded.

For those 12,020 departures, average delay is 23 minutes, ranging from 3 minutes up to 551 minutes.

The next step will consist in identifying codes which are an indication of an exceptional event with two characteristics :

- unpredictable delay (4)
- non-traffic dependent.

For instance : aircraft failure. Those cases will be discarded. We suggest they will later be processed for separate assessment of the statistical parameters (frequency, average delay and S.D.) in order to develop a complete model.
On the other hand, most cases will not be considered as an input :

- either they are clearly associated with events we are taking into account through other data (e.g. regulations, weather, airfield disruptions) ;
- or we assume them to be traffic-dependent (like passengers, baggage or local ATC causes) and we attempt to take them into account through traffic indicators.

For instance, we justify the assumption of traffic dependency about situations like "check-in error" :

- Number of check-in errors can be assumed to be, at least, proportional to the number of passengers. In fact, regarding the special case of "check-in error", their rate is probably increasing with the number of passengers to be processed, due to additional stress and workload.
- Regarding the delay induced, consequences of a check-in error are probably worse in the case of high passenger traffic.

Decisions applied to each IATA code are in the table below.

Codes "to be tested" are those we did not find easy to classify in one of both categories above. They have been entered in a first step and we checked that they generated outliers. There are several problems with those codes.

For instance, we might reasonably assume situations like "crew shortage" to be traffic dependent but, if this was the case the correct traffic indicator should reflect traffic at a global level (the airline). Instant Toulouse Blagnac traffic is not necessarily closely correlated to the global traffic of the airline at the given instant.

In the table, (1) stands for non-regulated flights and (2) for regulated flights, according to 3.2. Eventually, codes "to be tested" have been discarded.

(6) In addition, those cases should be discarded otherwise as non-standard turnarounds.

Code	Cause	Number of cases (2001)			Decision
		(1)	(2)	Total	
OTHERS					
01	Airline internal codes	0	0	0	Discarded cases
02		0	0	0	
09	Scheduled ground time less than declared minimum ground time	0	0	0	Not an input
PASSENGER AND BAGGAGE					
11	Late check-in (acceptance after deadline)	8	3	11	Not an input
12	Late check-in (congestion in check-in area)	2	3	5	
13	Check-in error	6	1	7	
14	Oversales, booking errors	5	1	6	
15	Boarding (missing checked-in passenger)	37	20	57	
16	Commercial publicity / Passenger convenience (VIP, press…)	3	3	6	To be tested
17	Catering order (late or incorrect order given to supplier)	1	1	2	
18	Baggage processing	1	2	3	Not an input
CARGO AND MAIL					
21	Documentation	0	0	0	To be tested
23	Late acceptance	0	0	0	
24	Inadequate packing	1	0	1	
25	Oversales	0	1	1	
AIRCRAFT AND RAMP HANDLING					
31	Aircraft documentation late / inaccurate (weight and balance)	3	0	3	Not an input
32	Loading / unloading (lack of staff...)	4	0	4	
33	Loading / equipment (lack of staff...)	0	0	0	
34	Servicing equipment (lack of staff…)	1	1	2	
35	Aircraft cleaning	5	3	8	
36	Fuelling / defuelling	1	1	2	
37	Catering	3	2	5	
39	Technical equipment (lack of staff, pushback...)	1	0	1	
TECHNICAL AND AIRCRAFT EQUIPMENT					
41	Aircraft defects	8	3	11	Discarded cases
42	Scheduled maintenance	1	0	1	Not an input
43	Non-scheduled maintenance	1	0	1	Discarded cases
44	Spares and maintenance equipment	0	0	0	To be tested
45	AOG spares	0	0	0	
46	Aircraft change for technical reasons	0	0	0	Not an input (6)
48	Scheduled cabin configuration / version adjustments	0	1	1	

DAMAGE TO AIRCRAFT AND EPD / AUTOMATED EQUIPMENT FAILURE					
51	Damage during flight operations (bird, turbulence…)	0	0	0	Discarded cases
52	Damage during ground operations	0	0	0	
55	Departure control	7	3	10	To be tested
56	Cargo preparation, documentation	0	0	0	Not an input
57	Flight plans	0	0	0	
FLIGHT OPERATIONS AND CREWING					
61	Flight plan	0	2	2	Not an input
62	Operational requirements (fuel, load alteration)	0	0	0	
63	Late crew boarding or departure procedures	3	0	3	To be tested
64	Flight deck crew shortage	3	6	9	
65	Flight deck crew special request	4	2	6	
66	Late cabin crew boarding or departure procedures	0	0	0	
67	Cabin crew shortage	0	1	1	
68	Cabin crew error or special request	0	0	0	
69	Captain request for security check	0	1	1	
WEATHER					
71	Departure station	0	0	0	Not an input (7)
72	Destination station	0	0	0	
73	En-route or alternate	0	1	1	
75	De-icing of aircraft	3	7	10	Discarded cases (8)
AFTM RESTRICTIONS / AIRPORT AND GOVERNMENTAL AUTHORITIES					
81	AFTM due to ATC en-route Demand / Capacity	21	538	559	Not an input
82	AFTM due to ATC Staff / Equipment en-route	1	11	12	
83	AFTM due to ATC Restriction at Destination Airport	1	12	13	
84	AFTM due to Weather at Destination	1	21	22	
85	Mandatory Security	6	8	14	To be tested
86	Immigration, customs, health	0	0	0	
87	Airport facilities	12	8	20	
88	Restrictions at airport of destination	0	0	0	Not an input
89	Restrictions at airport of departure (with or without AFTM)	8	7	15	

(7) If significant, we assume them to be taken into account through local meteorogical data and/or regulations.
(8) The risk might have been assessed with adequate meteorological parameters.

REACTIONARY AND MISCELLANEOUS					
91	Load connection (awaiting load from another flight)	15	1	16	Not an input
92	Through check-in error (passenger and baggage)	1	0	1	
93	Aircraft rotation (late arrival of aircraft)	111	116	227	
94	Cabin crew rotation (awaiting cabin crew from another flight)	0	0	0	To be tested
95	Crew rotation (awaiting crew from another flight)	0	0	0	
96	Operations control (aircraft change not for technical reasons…)	1	3	4	Discarded cases ([9])
97	Industrial action with own airline	1	5	6	Discarded cases
98	Industrial action outside own airline (excluding ATS)	0	0	0	
99	Other reason	7	3	10	

3.1.3 Configurations of airlines x station assistants

a) Station assistants :

The tasks held by station assistants are divided into three categories :

- "Passengers" (PAX) station assistant processes check-in to boarding on departures, unboarding (down to gate) on arrivals. Regarding the former tasks, performance might clearly depend on the passenger flow while the latter can be considered relatively negligible, except when parking is remote and unboarding performed by bus. It should be noticed that "remote boarding" would be taken into account as a separate indicator for flights in the sample but is not available for other flights.
- "Apron" (APR) station assistant processes catering, baggage and refuelling. Performance of the APR station assistant might thus depend on the passenger flow and we may assume that the instant number of passengers is a relevant measure of the instant task load, as far as baggage would be a constant parameter, whatever the passenger. However, we know the latter assumption is false since baggage load per passenger is different in holiday and non-holiday periods. Moreover, task load on departures could be drastically increased for flights sampled for baggage security controls. This parameter will be taken into account further, but only for flights in the sample (see 3.3. below).
- "Traffic" station assistant is in charge of coordination. Its performance could be affected by the aircraft traffic (as, for example ATC but not in the same range regarding block time) but probably not by the passenger traffic. Thus, it will not be taken into account later.

There are 5 station assistants operating at Toulouse Blagnac (listed below). For each flight in the sample, the same station assistant was in charge of "passengers", "apron" and "traffic". Thus, we did not have to process exceptional cases where the 3 categories are not consistent. Those cases are responsible for the differences in the number of passengers processed (table below), depending on the type of assistance (APR or PAX) and the direction of the flight.

([9])In addition, those cases should be discarded otherwise as non-standard turnarounds.

Station assistant	Departures (1)	PAX Assistant		APR Assistant		Average number / hour
		Dep.	Arr.	Dep.	Arr.	
AFR	1510	1549333	1557536	1545210	1554031	178
AVP	63	74873	76202	74873	76202	9
LIT	621	246496	243244	246496	243244	28
PAA	121	213563	208788	217686	212293	25
SAA	831	658767	643108	658771	643108	75

Number of departures (1) is the number of departures in our sample for year 2001, both regulated and non-regulated flights, where FPL data have been successfully matched.

b) Airlines x station assistants :

Airline	Station assistant				
	AFR	AVP	LIT	PAA	SAA
AFRLFLL	205				
AFRLFMN	41				
AFRLFPG	283				
AFRLFPO	927				
AFRLFQQ	54				
BAWEGKK		63			62
CRXLSZM			75		
DLHEDDF			123		
DLHEDDM			124		
KLMEHAM				121	
LIBLFJL					58
LIBLFMK					85
LIBLFPO					518
LIBLFRS					108
LITLFMN			188		
SABEBBR			111		

Table above shows that, for each airline in the sample, a single assistant throughout the period generally performs station operations.

3.1.4 Traffic indicators

a) Building a base of instant flows :

Each minute between Jan. 1st 2000 and June 30th 2000 on the one hand and between Jan. 1st 2001 and June 30th 2001 on the other hand refers to an index starting at 0 on Jan. 1st 2000 at 00:00 TU with a step of one per minute. It is then quite simple to build a basis of instant flows (aircraft and passenger traffic).

For aircraft, in the case of arrivals and departures, one (movement) is affected to the minute index which is linked to actual block time. In the case of local training and trial flights, which are not negligible at Toulouse airport (for the purposes of Airbus industries), the share of the total number of movements (for an individual training or trial session) divided by the number of minutes (flight duration) is affected to each minute index between the beginning and the end of the flight. Aircraft flows are detailed in arrivals, departures and local training. Although not very relevant, the sum of instant flows on arrival and departures is up to 5, which means that up to 5 aircraft have been reaching or leaving block in the same minute throughout the days sampled.

For passengers, the number of passengers for each individual flight is affected to the minute index which is linked to the actual block time. Passenger flows are detailed in arrivals and departures. They will be further detailed by the station assistant.

b) Building a base of significant flows out of the base of instant flows :

Significant flows are aircraft and passenger flows as a measure of the instant load for operators handling traffic (local ATC and station assistants). Significant flows are assessed as the sum of instant flows around each minute index, the range depending on the type of traffic :

Traffic	Type of movement	Time range (minutes around reference*)	
		Starting at :	Finishing at :
Aircraft	Arrival	0	+ 30
	Departure	- 15	0
	Training	0	0
Passengers	Arrival	- 60	0
	Departure	- 45	0

The reference (*) linked to a minute index is scheduled block time for both non-regulated and regulated flights.

Considering passenger load, significant flow has to do with analysis of movements on departure only. We assume that most passengers entered the check-in area within 45 minutes before scheduled block time. Thus, all flights on departure actually leaving blocks within 45 minutes before scheduled block time are likely to have interfered. This value is brought up to 60 minutes for flights on arrival because we assume passengers on a special flight may occupy the terminal within 15 minutes after its actual block time.

Considering traffic load, our aim is to assess local ATC-load at scheduled block time for flights on departure. We assume that a flight on departure interacts significantly with local ATC during 15 minutes after its actual block time whereas a flight on arrival interacts significantly with local ATC during 30 minutes before its actual block time. Regarding local flights, which are not negligible at Toulouse Blagnac, we compute the number of current training flights (usually one at a time) at scheduled block time. But, in addition, we have to account for the fact that a training flight induces, potentially, an extra departure and/or an extra arrival (except if starting and/or finishing to/from another aerodrome). In other words, arrivals and departures for training flights are counted in the same way as ordinary movements and, in addition, we store for each minute index the number of current training flights.

c) Detailing passenger flows by station assistant :

Passenger instant flows have been detailed by station assistants and added up according to the same rule depending on the type of movement :

Type of movement	Time range (minutes around reference*)	
	Starting at :	Finishing at :
Arrival	- 60	0
Departure	- 45	0

As above, the reference (*) linking to a minute index is scheduled block time for both non-regulated and regulated flights.

Passenger loads are, for each station assistant, detailed in Passenger and Apron assistance operations. "Passengers" operations should not be considered a significant load on arrival : they just consist in guiding passengers to exits. However, we have calculated the following four indicators : PAX_DEP, PAX_ARR, APR_DEP and APR_ARR.

3.2 Processing en-route traffic and slot allocation

3.2.1 Building a base of flight plan data

The French national archive database for flight plans data was submitted to extractions. Amongst requested information, the following were processed and stored with an appropriate foreign key in order to match them to movements in our reference database :

- Estimated Of Block Date (EOBD) ;
- Estimated Of Block Time (EOBT) ;
- Date / time of slot, explicitly Calculated Take Off Date (CTOD) and Calculated Take Off Time (CTOT) ;
- First and second regulations.

Flight plans are stored in the national archive files under three consecutive states: “initial”, “scheduled” and “performed”. “Initial” (regarding initial flight plan filed) and “performed” (last review of the flight plan after e.g. regulations have been applied) states were requested and processed. Flight plans stored are either FPL (most cases) or simple instant “forms” (FII or FIH) filed by local ATC on the operator’s request (for instance, when the flight is delayed but ready to go and not submitted to any regulation).

Only departure segments were taken into account. The foreign key is a string including the date (yyyymmdd) and the flight code (e.g. CRX763). Decoding was necessary to a very large extent to make correspond IATA flight codes (in our reference file) with codes appearing in flight plans archives. A few occurrences in flight plan archives (13) failed to be decoded, most of them referring obviously to non -commercial flights (like setting up). The foreign key should be unique. Nevertheless, in many cases (190), it appeared in several occurrences (up to 5). Thus, lines with the same key had to be matched together since they referred to the same flight, the latter being associated with several FPL filed consecutively.

In order to make relevant information available for further analysis, the following indicators have been copied or computed from the original FPL file :

- flight identifier (a single occurrence of the date/flight key);
- first EOBD/EOBT filed by the operator;
- shift of EOBT i.e. difference (in minutes) between the first and the last EOBT filed by the operator;
- ATC delay i.e. difference (in minutes) between the last EOBT filed by the operator and CTOT (slot allocated by CFMU), if any;
- First and second (if any) regulation identifier(s), only if the flight has been subjected to a slot.

EOBD/EOBT values are extracted from “initial” state of FPLs. In the “performed” state, these values refer to (a) the actual take off date/time if they have been stored in the STIP ([10]) computer i.e. when a slot has been allocated (EOBT being then the CTOT) or (b) calculation on the basis of the initial FPL and standard taxiing time. Thus, we did not take them into account (since we base assessment of delays on block times and actual block time is available to us). So, in most cases (a single FPL having been filed), shift-EOBT is zero. This indicator attempts to assess the share of the total delay, as far as it is valuable through FPL archive files, generated by the operator itself. It takes strictly positive or negative values each time a FPL has been refiled (up to 4) for a particular flight. It follows that ATC-delay is zero (and no regulation mentioned) as far as a flight has not been submitted to a regulation consecutively to the last FPL filed, even if it has been submitted to a slot for a previous FPL.

([10]) STIP is the initial flight plans processing system which all ATC processing is based on.

For the year 2001, the rough number of lines is 3,441 but taking into account multiple occurrences and explicitly cancelled flights, the net number is 3,162 vs. 3,451 departures in our reference file : as a result, 3,146 movements in the sample reference file now have information from FPL archives ([11]). AFR movements to LFRN (performed under a different operator IATA code) were not extracted. The same problem occurred with AFR movements to LFQQ during the second quarter of the year. CRX movements to LSZM were not extracted in January and February, LFSB French location indicator being used in the National Archive files instead of LSZM. All those movements are lost for ever unless further extraction that would require restoration of stored away data.

In fact, 5 cases only bear a shift-EOBT and an ATC-delay both different from zero. We should check whether that number underestimates the real number of cases where an initial delay related to a non-ATC cause is greater as a result of an ATC regulation when the aircraft would be ready to go.

Considering rough data, first EOBT is, as expected, equal to scheduled time (3.123 cases) : 23 departures only have an EOBT different from the scheduled time but the difference does not exceed 10 minutes in most cases ([12]).

3.2.2 Analysis of ATC delays

For further analysis, the reference file has been divided into two, depending on the existence of a regulation.

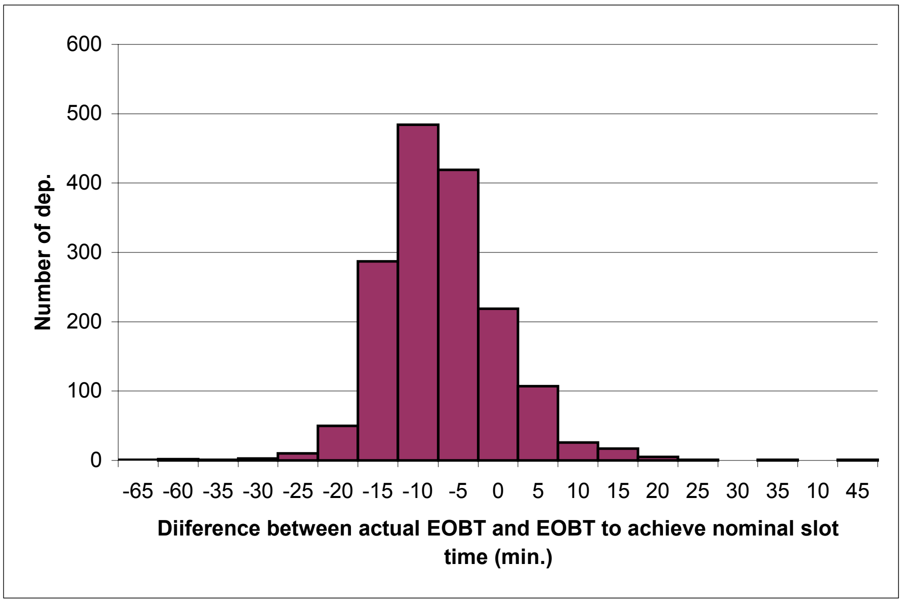
"NON_REG" file contains 1,508 records, depicting departures that are not affected by a regulation ([13]). For those departures, overall delay ranges from –25 to +207 with an average of 7.6 minutes.

Departures submitted to a regulation are in "REG" file. For those departures, we now have to take into account taxiing time in order to compute the ATC-delay. According to CFMU parameters, taxiing time at Toulouse Blagnac is supposed to be 5 minutes, whatever the runway in use. This is consistent with the estimate of taxiing time by ATC local agents (interviews). We checked this estimate : in the reference file of regulated flights (6 weeks out of 6 months), the average ATC-delay i.e.

CTOT - (Scheduled Block Time + 5)

is on average 19.55 minutes (from –10 up to 133) whereas, for the whole first six-month period of 2001 and for all of the flights on departure, CFMU statistics give an average ATC-delay of 19.76 minutes per delayed flight. ATC-delay refers to block time to be respected in order to achieve the nominal slot time.

([11]) The difference (3.146 to 3.162) is, for instance, due to non-commercial flights (like setting up) operated under the airline code, which are also subjected to FPL.
([12]) Given that (a) it is not necessary to refile a flight plan for a change of 10 minutes in scheduled time and (b) all routes concerned are not likely to be submitted to regulations, we think that those cases are intentional or unintentional differences between the Repetitive flight plan (RPL) filed and the scheduled time eventually published by the operator. Fifteen out of those 19 cases affect the same airline.
([13]) Amongst those departures, a few have nevertheless significant information at FPL-level, since EOBT has been changed.



Given there is a window of –5' to +10' around the nominal slot time, differences of less than 10 minutes (97 %) allow the upper edge of the slot to be achieved. Departing before the lower edge of the slot window essentially depends on the possibility for ATFM authorities to improve a slot.

Conversely, CFMU data are necessary to decide whether flights leaving blocks after the upper limit of the slot window have either been delayed (for the share beyond SLOT time) for non-ATC reasons or have been subjected to further regulation. This applies in fact to every flight whose actual block time is after the "slot" block time : if only ATC causes were effective, what would stop the flight from departing at the "slot" block time ?

3.3 Qualifying and quantifying passenger process on departure

Data were requested from airport management and airlines for each line in the sample and for any change throughout the period :

Qualify	- location of check-in positions (hall 1 or 2) - pre-check in device - boarding (in-touch or remote by bus)
Quantify	- Number of check-in positions - Flow rate through security process, number of positions - Number of boarding positions

In fact, having discussed with the airport management staff the actual availability of data, the relative (possible) influence on delays of subsystems and stages in the process, the fact that incidents (e.g. system failure) should be mentioned otherwise in the ATS/airport database under IATA codes, we decided to give a value to the following indicators for flights on departure :

3.3.1 Location of check-in positions

For each flight on departure, the location of check-in positions in Hall 1 or Hall 2 is recorded.

3.3.2 Check-in device

The location (within Hall 1 or 2), the number of check-in positions and the time allocated to check-in for each flight are submitted to a number of rules reached by common agreement between the airport management and airlines. We did not find it necessary to define indicators for accurate rules. In fact, it appeared possible to define a single indicator assessing if the global time allocated to check-in for a special flight was adequate.
For each flight, operators define a "standard module size" (the number of seats offered) and the airport management quantifies the passenger flow through check-in. For instance, AFRLFPO is supposed to offer 142 seats and check-in passengers at a rate of 65 passengers / hour.
We define the ***CHECK IN indicator*** as follows :

(Number of seats – Actual number of pax) / Rate * 60

It is thus a measure of the excess (or the lack) of minutes observed for a special flight, given the standard number of check-in positions and time allocated regarding the standard module size and performance at check-in on the one hand, and the actual number of passengers on the other hand.

As a consequence, the value of this indicator is low when the demand – the number of passengers to be boarded in a special flight – is high. It may be negative if the number of passengers is above the standard number for the airline. Conversely, the highest value for the CHECK IN indicator would be reached if the flight was empty : this value would then be the time (in hours) considered to be the standard time to complete check-in for the flight regarding the airline.

3.3.3 Boarding

For each flight on departure, the type of boarding (In-touch or Remote by bus) is coded.

3.3.4 Baggage compartment security controls

Before September 2001, baggage compartment security control was carried out every day within a period randomly determined out of :

- Period 1 : before 09:00
- Period 2 : from 09:00 to 13:00
- Period 3 : from 13:00 to 17:00
- Period 4 : after 17:00

All the flights scheduled within the chosen period were submitted to baggage compartment security control. Thus, approximately 25 % of flights were checked. In fact, we did not process actual data for every flight in the sample but were given, for each day, the period when baggage compartment security control was carried out. We validated the method with actual data out of 2 weeks, one in winter schedule, and the other in summer schedule. Out of 946 cases, only 9 were misclassified (9 flights supposed to have been submitted to baggage compartment security control regarding their scheduled time were not actually checked).

3.4 Capacity

3.4.1 Low visibility

We processed a text file issued by the local station of climatology which gave details, during the days sampled, parameters with a step of one hour (2,016 hours over 84 days).

Occurrence of LVP situations has been assessed by taking into account, per hour, RVR (runway visual range) and height of the cloud cover (HCC). For the 84 sampled days, the number of hours in LVP is only 9,and only 2 in 2001.

LVP	RVR (m)	HCC (ft)	Number
Level 1	400 < RVR <= 1000	<= 200	7 hours
Level 2	RVR <= 400		2 hours

LVP has been translated in terms of capacity (see 3.4.4).

3.4.2 Other meteorological events :

We have 4 hours with a storm in the final approach segments or on the airfield itself. We checked that there is no significant effect regarding delay on departure. Throughout the days sampled, there is not a single hour with snow on the ground. Thus, these parameters have not been taken into account later.

3.4.3 Airfield disruptions

Commercial aircraft are parked on Blagnac I and Blagnac II aprons. The latter is entirely dedicated to commercial traffic whereas only a portion of the former is used for commercial aircraft.

Generally speaking, unless there are bad weather conditions, 14R/32L runway will be preferred for landings and 14L/32R runway for takeoffs. Thus, 45 movements per hour are theoretically possible with a landing frequency of one aircraft for every 2’36’’.

Special events having caused airfield disruptions have been recorded.

DATE	UTC TIME	RWY OR TWY	EVENT
19/06/2000	0000-2359	P40 - P50 - T50	WORKS
20/06/2000	0000-2359	P40 - P50 - T50	WORKS
21/06/2000	0000-2359	P40 - P50 - T50	WORKS
22/06/2000	0000-2359	P40 - P50 - T50	WORKS
23/06/2000	0000-2359	P40 - P50 - T50	WORKS
24/06/2000	0000-2359	P40 - P50 - T50	WORKS
25/06/2000	0000-2359	P40 - P50 - T50	WORKS
18/01/2001	0630-1600	15R/33L	REPAIRS
20/02/2001	0850-1630	15R/33L - S2 - S3	WORKS
18/06/2001	0900-1200	15R/33L	REPAIRS
20/06/2001	0708-0801	15L/33R	OTHER
20/06/2001	0843-0950	15L/33R	OTHER

Those events have usually reduced the theoretically possible number of movements per hour by a third (45 to 30).

3.4.4 Capacity

Capacity is a computed quantitative variable ranging from 0 (closure of the airport, no case during the 84 days) to 1 (maximum capacity, standard). Local ATC instructions describe 12 cases, depending on the general traffic device and disruptions, and give for each case : the landing rate, the number of arrivals per hour, and the total number of movements (arrivals and departures) per hour. Theoretical capacity is the ratio of the total number of movements in each case to the maximum number of movements (i.e. 45).

Meteorological events (LVP) and airfield disruptions which those cases are based on, are known with a step of one hour, each movement on departure has been allocated the theoretical capacity of the current hour on its scheduled block time.

Case	General device	Disorder	Landing rate	Arrivals / hour	Total Mvts / hour	Theoretical capacity
0	All means available	None	2 min 36	23	45	1.0
1	QFU 14 14R and 14L available	Closure M4	3 min 26	17	39	0.9
2	QFU 14R T.O. on 3000 m (TWY M10)	Closure 14L	4 min	15	30	0.7
3	QFU 14R T.O. on 3000 m (TWY M10)	Closure 14L Closure M4	4 min 30	13	26	0.6
4	QFU 14R T.O. on 3000 m (TWY M10)	Closure M10	6 min	10	20	0.4
5	QFU 14R T.O. on 3500 m (threshold)	Closure 14L	4 min 30	13	26	0.6
6	QFU 14R T.O. on 3500 m (threshold)	Closure 14L Closure M4	4 min 30	13	26	0.6
7	QFU 14L	Closure 14R	3 min 20	17	34	0.8
8	QFU 32L	Closure 32R	3 min 45	16	32	0.7
9	QFU 32L	Closure 32R Closure M8	4 min 30	13	26	0.6
10	QFU 32R	Closure 33L	3 min 30	17	34	0.8
11	QFU 14L available for T.O.	LVP	5 min	12	25	0.6
12	QFU 14L not available for T.O.	LVP	7 min 30	8	16	0.4

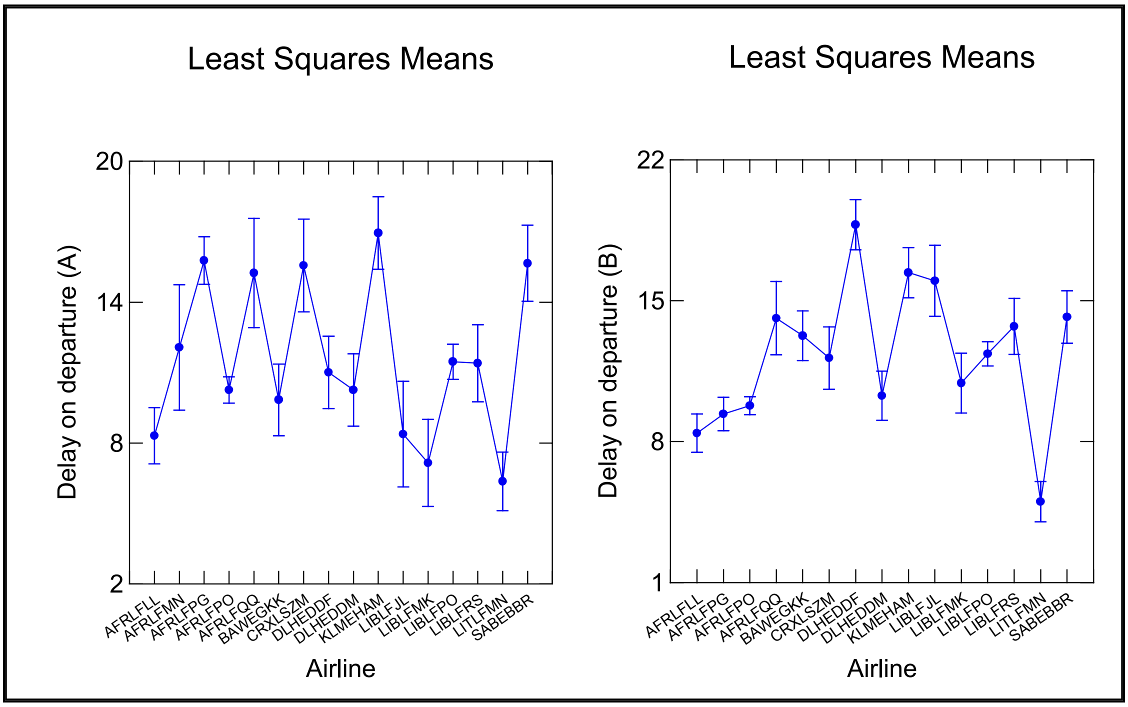
T.O. take off
14L, 14R, 32L, 32R are runways ; M4, M8, M10 are taxiways

4. Correlations

In order to build a model of delays on departure, further analysis has been processed. Unless mentioned, results are derived from 2001 data.

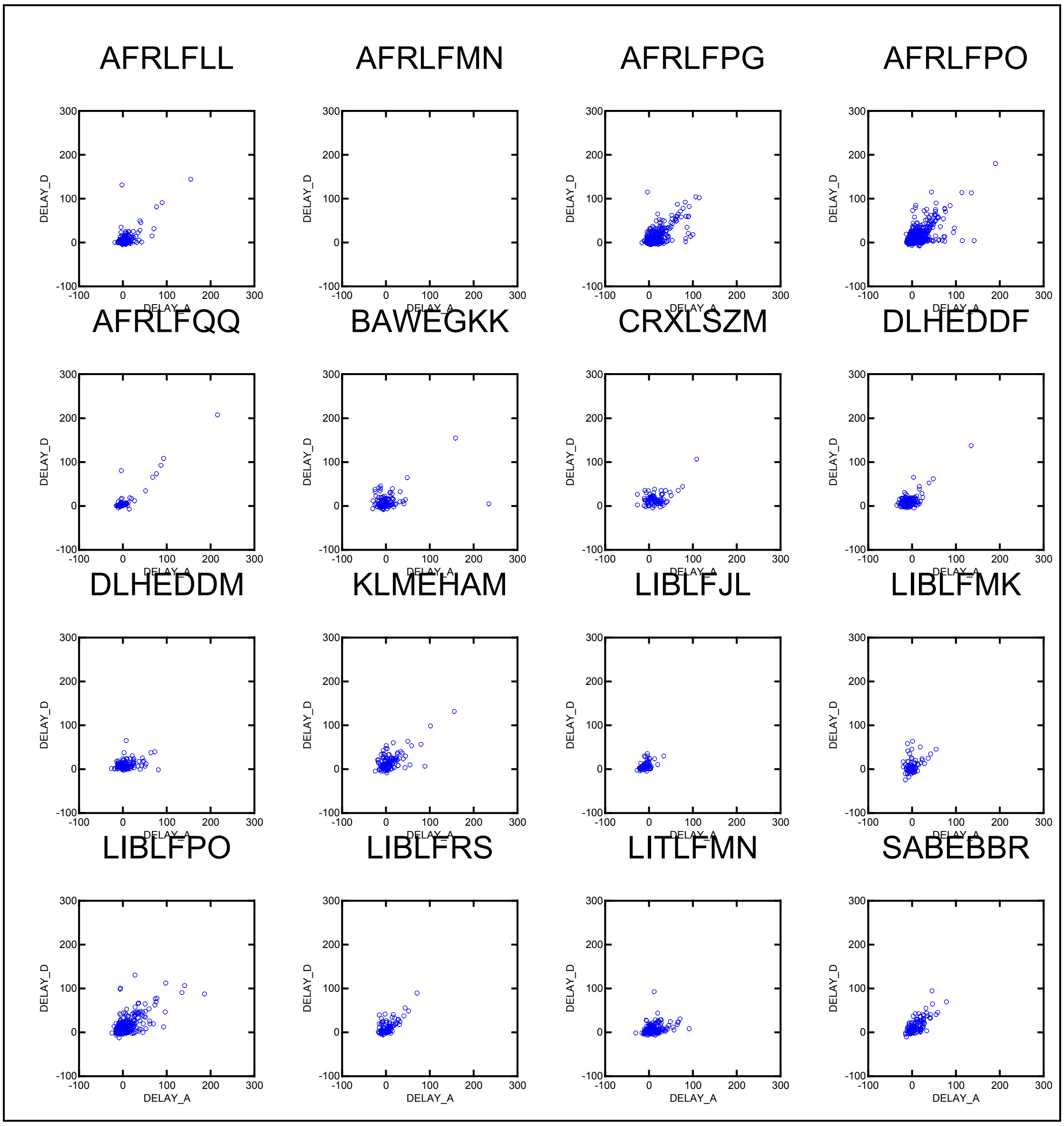
4.1 Influence of the airline

Influence of the airline on departure delay is significant. Rough average delay per airline ranges from 6.4 minutes to 16.9 minutes (see graph. below, left). However, covariation of the delay on arrival adds unwanted variability, so delay on arrival was entered as a covariate. F-ratio is then increased and significant differences between airlines are pointed out in the figure below (right).



Moreover, regarding variability of delays on departure, there is a significant interaction between the airline and the delay on arrival.

This is reflected in very different patterns, regarding the (airline x destination), delay on departure against delay on arrival (see the figures here below).



4.2 Influence of station stop-over time

Regarding the(airline x destination) a reasonable assumption was that it could affect delay on departure because of station stop-over time, the average station stop-over time supposed more or less to be necessary to the completion of the scheduled departure time.

Station stop-over time has been computed as the difference between scheduled block time on departure and scheduled block time on arrival, for each flight.

In fact, correlation between station stop time and delay on departure is very poor (R is 0.049). Delay on departure might be significantly lower for station stop-over times between 100 and 250 minutes but :

- For station stop-over times under 100 minutes, a trend is hard to find ;
- For station stop-over times over 250 minutes, delays on departure may increase by up to 40 minutes or more.

4.3 Influence of delay on arrival

Delay on arrival is supposed to be a major factor of delay on departure. A previous study at Toulouse Blagnac highlighted the correlation between both variables. However, it also showed that there is an important dispersion of values for delays up to 100 minutes (see figure here below, all flights in the sample, R is 0.716). Thus, delay on arrival cannot only account – by far – for the variability of delays on departure. It is clearly not sufficient in an explanatory model (and, a fortiori, in a prediction model).

Segmentation of our reference file regarding regulations (see Processing en-route and slot allocation) has been applied.

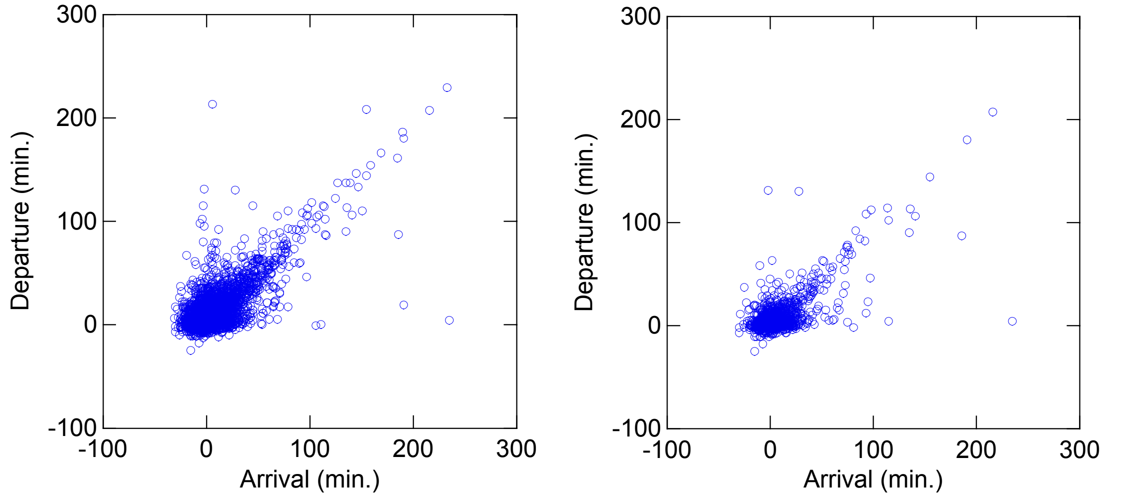
4.3.1 Non-regulated flights

The figure here below shows the distribution of delays on departure against delays on arrival for non-regulated flights. Correlation is close to the correlation when computed for both regulated and non-regulated flights (0.699).

Dispersion is still large, some points still being exceptionally far from predicted values. On the other hand, departure time cannot be constrained by a slot anymore.

However, in order to “clear” the relationship between departure time and delay on arrival, we still have to remove :

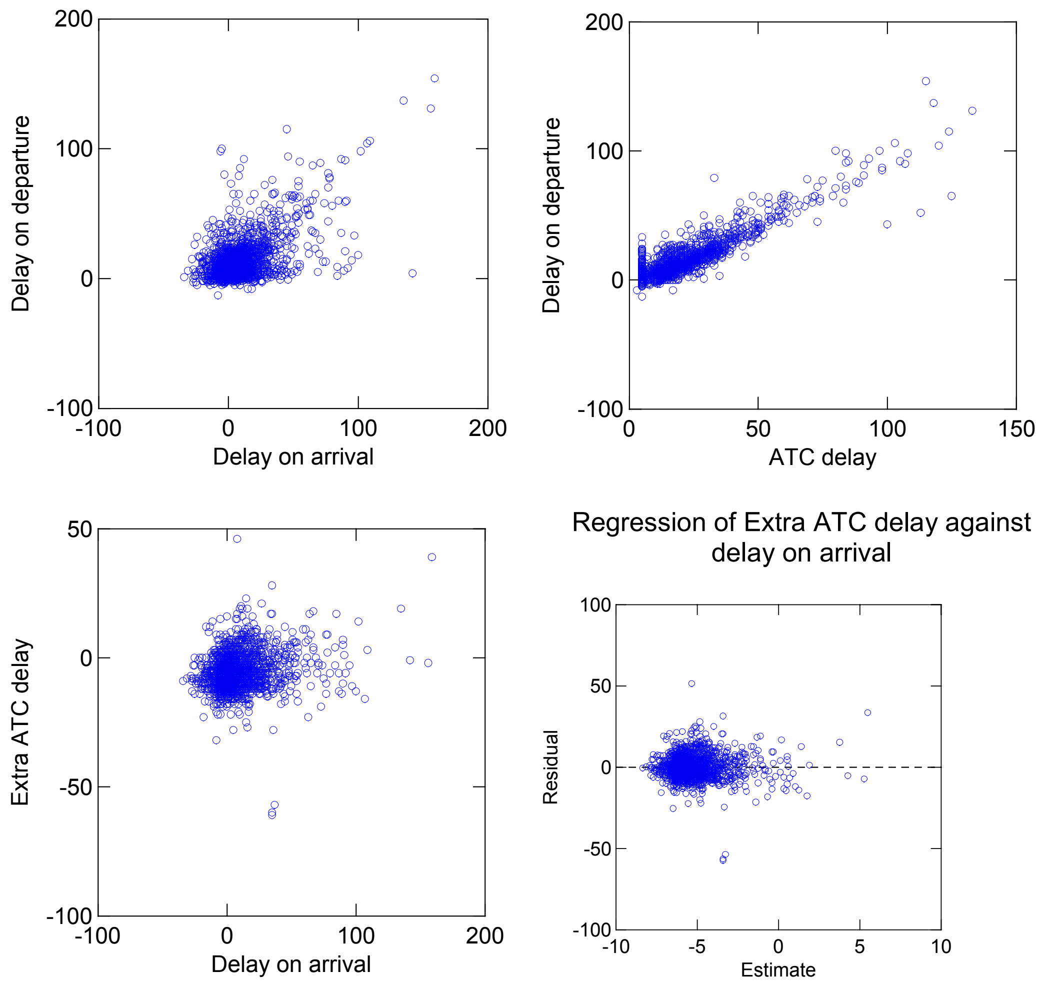
- Flights on departure with delay IATA codes indicating an exceptional event ;
- Non-standard turnarounds: We assume that these turnarounds are associated with late arrival or major failure of the standard turnaround, and the result, rather than the cause, of an initial delay. Of course, the principle of the turnaround identifier is to link to the plane which actually performs the turnaround. But, in the case of non-standard turnaround, station stop-over time is not standard (regarding the flight on departure) : an aircraft on departure (e.g. at 10:45) performing a non-standard turnaround may have been greatly delayed on arrival (e.g. by 50 minutes) but be ready to go on scheduled block time for departure (if, for instance, it was scheduled on arrival at 07:10).



All flights in the sample (years 2000 and 2001)

Non-regulated flights (year 2001)

4.3.2 Regulated flights



The figure here above shows that :

- Quality of the rough correlation between delay on departure and delay on arrival (when regulations were not taken into account) was to a large extent due to high correlation for non-regulated flights.

- Correlation of delay on departure to ATC-delay is very high (0.903) while the correlation of delay on departure to delay on arrival is only 0.540.

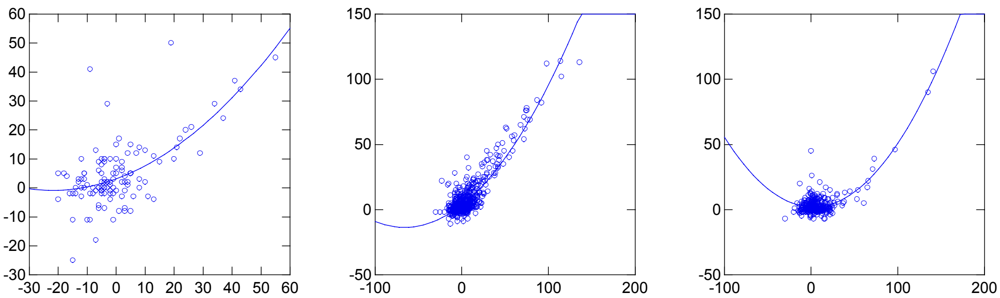
- We define extra ATC delay as the difference between delay on departure and ATC delay (under the constraint of the slot). Figure above shows that extra ATC delay is not correlated to delay on arrival (R is 0.193).

However,the following checks are required :

- Remove non-standard turnarounds, if any ;
- Remove flights on departure with delay IATA codes indicating an exceptional event ;
- Check with reference to CFMU archives that slots have not been further modified (positive or negative shift of the slot, e.g. through SIP message).

4.4 Delay on arrival and station stop-over time : interaction, quadratic effect

An exploratory analysis shows that the regression of delay on departure against delay on arrival has to be analysed for three different situations depending on station stop time : up to 30 minutes (left), over 30 minutes up to 60 minutes (centre) and over 60 minutes (right).



4.4.1 Station stop-over time up to 30 minutes

The model of delay on departure for flights with station stop-over time up to 30 minutes is:

```
Dep Var: DELAYD    N: 117    Multiple R: 0.712    Squared multiple R: 0.507
Adjusted squared multiple R: 0.494    Standard error of estimate: 8.134
```

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P
CONSTANT	41.529	9.410	0.000	.	4.413	0.000
DELAYA	0.433	0.084	0.495	0.477	5.169	0.000
STOP_TIME	-1.348	0.329	-0.277	0.952	-4.094	0.000
DELAYA*DELAYA	0.008	0.003	0.265	0.494	2.823	0.006

In addition, the analysis shows that the effect of interaction between Station Stop Time and Delay on Arrival is not significant.

4.4.2 Station stop-over time more than 30 minutes up to 60 minutes

The model of delay on departure for flights with station stop-over time from 30 to 60 minutes is:

```
Dep Var: DELAYD   N: 615   Multiple R: 0.915   Squared multiple R: 0.837
Adjusted squared multiple R: 0.836   Standard error of estimate: 6.487
```

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P
CONSTANT	15.627	1.937	0.000	.	8.069	0.000
DELAYA	0.544	0.027	0.618	0.291	20.442	0.000
STOP_TIME	-0.297	0.048	-0.103	0.976	-6.241	0.000
DELAYA*DELAYA	0.004	0.000	0.341	0.295	11.333	0.000

The analyse shows that the interaction of between Station Stop-Over Time and Delay on Arrival is significant for this segment.

4.4.3 Station stop-over time over 60 minutes

The only significant effect is now the quadratic effect of delay on arrival as shown in the model here below:

```
Dep Var: DELAYD   N: 338   Multiple R: 0.844   Squared multiple R: 0.713
Adjusted squared multiple R: 0.712   Standard error of estimate: 5.152
```

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P
CONSTANT	1.960	0.287	0.000	.	6.841	0.000
DELAYA*DELAYA	0.005	0.000	0.844	1.000	28.901	0.000

4.5 Categorical variables

We have processed analysis of variance for delay on departure depending on categorical variables. Possible categorical variables are :

- the airline ;
- the airline x destination ;
- the season (winter or summer) ;
- the month ;
- the day of the week ;
- the scheduled hour of departure (in local time) ;
- the hall in terminal (1 or 2) ;
- flight submitted to baggage compartment security control ;
- the type of boarding (in-touch or remote).

Month is nested in season. Airline x destination should be nested in airline but several airlines have only one destination in our sample. Thus, airline has not been taken into account. Given that the design is greatly unbalanced, files have been submitted to General Linear Model (GLM) process.

The most noticeable results are :

a) Season and month :

Month is not significant once the season has been taken into account.

b) Baggage compartment security control :

Although expected, there is no significant effect.

c) Ski charters :

Although expected, there seems to be no significant consequence of disorders induced by ski charters on Sundays in winter. Hall could have been affected because in this particular situation, several flights have the check-in moved from Hall 2 to Hall 1 but this effect is not significant.

d) Scheduled hour :

We observe significant effects of the scheduled hour. We are next planning to assess the direct effect of the scheduled hour (through variations in time of ATC, assistance and airport management devices) and indirect effects through variations in traffic.

5. Building the MODELS

The computation of the numerical models was based on a segmentation of the file regarding stop-over time (up to 30 minutes, over 30 up to 60 minutes, over 60 minutes, night stops). Only non-regulated flights were taken into account.

As shown in the previous section, the computation of the 4 models should include the quadratic effect of the Delay on arrival. The station stop-over time effect is included for stop-over times up to 60 minutes.

5.1 Station stop-over time up to 30 minutes

The table here below gives the number and the distribution airlines/assistant for the flights with station stop-over time up to 30 minutes:

	Assistant		
Airline	LIT	SAA	Total
LIBLFJL		27	27
LIBLFMK		51	51
LIBLFRS		47	47
LITLFMN	13		13
SABEBBR	10		10
Total	**23**	**125**	**148**

We found several outliers, most of them being LIBLFMK flights with great delays on departure regarding the delay on arrival. We may suspect these flights to have been awaiting the LIBLFPO connection flight.

After removing outliers, the model is as follows :

Dep Var: DELAYD N: 143 Multiple R: 0.894 Squared multiple R: 0.799
Adjusted squared multiple R: 0.788 Standard error of estimate: 4.696

Effect	Coefficient	Std Error	Std Coef	Tolerance	T	P
CONSTANT	32.592	5.587	0.000	.	5.834	0.000
DELAYA	0.406	0.043	0.521	0.487	9.424	0.000
STOP TIME	-0.842	0.196	-0.178	0.866	-4.291	0.000
SATD	10.718	3.435	0.124	0.947	3.120	0.002
CHECK_IN	-0.120	0.025	-0.220	0.704	-4.792	0.000
LIBLFMK	-7.920	0.908	-0.366	0.848	-8.725	0.000
SABEBBR	4.730	1.726	0.119	0.796	2.741	0.007
DELAYA*DELAYA	0.011	0.001	0.419	0.512	7.775	0.000

The other effects are far from being significant. Given that "load" indicators are not entered, introducing a sum of "load" on arrival and "load" on departure does not improve the model. With the noticeable exception of "Saturday", none of the "time scale" indicators is entered.

Although we expected it, there is no significant interaction between "Sunday" and "Winter" due to ski charters. Regarding terminal factors (hall, baggage compartment security control and type of boarding), all are far to be entered.

The main features of this model are :

- The proportion of the total variation in Delay on departure accounted for by the variation in the dependent variables is close to 80 % vs. 54 % if taking into account only the simple effect of the delay on arrival.
- It includes several "desirable" quantitative variables : delay on arrival (simple and quadratic effect), stop-over time and check-in.
- Effects of the "load" carried out by the station assistants are far from being significant.

Effects of the quantitative variables may be summed up as follows.

- A 10-minute delay on arrival generates an increase in the delay on departure by 4 minutes for the simple effect and by 1 minute for the quadratic effect.
- Reducing station stop-over time from 30 minutes to 25 minutes generates an increase in the delay on departure by 4 minutes.
- An increase in the demand at check-in by 10 minutes generates an increase in the delay on departure by more than 1 minute. Given the rate of passengers / hour at check-in, this is equivalent to an increase of 5 to 8 passengers for the flights concerned.

5.2 Station stop-over time of more than 30 minutes up to 60 minutes

The table here below gives the number and the distribution airlines/assistant for the flights with station stop-over time between 30 and 60 minutes:

	Station assistant					
Airline	AFR	AVP	LIT	PAA	SAA	Total
AFRLFLL	70					70
AFRLFMN	8					8
AFRLFPG	42					42
AFRLFPO	310					310
AFRLFQQ	37					37
BAWEGKK		12			11	23
KLMEHAM				13		13
LIBLFJL					7	7
LIBLFPO					179	179
LIBLFRS					10	10
LITLFMN			8			8
SABEBBR			21			21
Total	**467**	**12**	**29**	**13**	**207**	**728**

The model of delay on departure for this segment is given here below:

Dep Var: DELAYD N: 728 Multiple R: 0.941 Squared multiple R: 0.885
Adjusted squared multiple R: 0.882 Standard error of estimate: 5.524

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P
CONSTANT	39.399	5.326	0.000	.	7.397	0.000
DELAYA	0.564	0.022	0.639	0.270	26.087	0.000
STOP TIME	-0.448	0.063	-0.145	0.387	-7.100	0.000
SATD	2.511	0.700	0.048	0.894	3.585	0.000
HR13	-2.829	0.952	-0.040	0.891	-2.972	0.003
HR20	2.511	0.658	0.055	0.785	3.816	0.000
CAPA	-14.813	4.640	-0.042	0.952	-3.192	0.001
CHECK_IN	-0.081	0.006	-0.263	0.426	-13.493	0.000
TFC_DEP	-0.340	0.134	-0.035	0.827	-2.533	0.012
PAX_DEP	0.003	0.001	0.038	0.577	2.286	0.023
ATRU_PAX_D	-0.007	0.002	-0.059	0.476	-3.213	0.001
LIBLFPO	3.387	0.691	0.091	0.473	4.900	0.000
LIBLFJL	10.647	2.129	0.065	0.971	5.001	0.000
AFRLFLL	-5.206	0.830	-0.095	0.700	-6.270	0.000
AFRLFMN	5.540	2.110	0.036	0.866	2.625	0.009
AFRLFPG	4.498	1.204	0.065	0.532	3.737	0.000
BAWEGKK	-4.532	1.430	-0.049	0.670	-3.168	0.002
DELAYA*DELAYA	0.003	0.000	0.324	0.291	13.738	0.000

We did not take interaction (station assistant x “load”) into account because, on the one hand, multiple correlation and standard error of estimate are not really worse and, on the other hand, it will be easier to handle for computations and future adjustments of the parameters (device required in order to estimate parameters in the future should be simple). However, we must keep in mind that 2 station assistants (AFR for AFR and SAA for LIB) weigh 93 % of the sample and AFR alone 64 %.

All of the other effects are far from being significant, with the exception of aircraft traffic on departure (F>3, but with a negative correlation to delay on departure). The main features of this model are :

- The proportion of the total variation in Delay on departure accounted for by the variation in the dependent variables is close to 90 % vs. 78 % if taking into account only the simple effect of the delay on arrival.
- It includes several “desirable” quantitative variables : delay on arrival (simple and quadratic effect), stop-over time, check-in, capacity and some of the “traffic” effects.
- The sign of correlations between “traffic” effects and delay on departure still raises questions. On the one hand, the total number of passengers on departure within the 45 minutes before scheduled time has a positive coefficient. On the other hand, aircraft traffic on departure (within 15 minutes before scheduled time) and the total number of passengers on departure handled by the station assistant for the flight (within 45 minutes before scheduled time) are negatively correlated with delay on departure. This result will be discussed later.

Effects of the quantitative variables may be summed up as follows.

- A 10-minute delay on arrival generates an increase in the delay on departure by 5.6 minutes for the simple effect and by 0.3 minute for the quadratic effect, resulting in a total increase by 6 minutes.
- Reducing station stop-over time from 60 minutes to 45 minutes generates an increase in the delay on departure by 6 minutes.

- An increase in the demand at check-in by 12 minutes generates an increase in the delay on departure by 1 minute. Given the rate of (passengers / hour) at check-in, this is equivalent to an increase of 6.5 to 13 passengers for the flights concerned.
- Reducing the ATC/airfield device capacity from 100 % (standard, full capacity) to 70 % (like closure of runway 32R) generates an increase in the delay on departure by 4 minutes.
- An increase by 400 of the number of passengers actually departing within the 45 minutes before scheduled time (indicator of terminal congestion) generates an increase in the delay on departure by 1 minute.
- But, out of the former number, if 150 more passengers have been handled by the particular station assistant that processes the flight (station assistant load indicator), then delay on departure would decrease by 1 minute.

Last, an increase by 3 of the number of flights on departure within the 15 minutes before scheduled time (local ATC load indicator) results in a drop in the delay on departure by 1 minute.

5.3 Station stop-over time over 60 minutes

The table here below gives the number and the distribution airlines/assistant for the flights with station stop-over time over 60 minutes:

Airline	Station assistant			Total
	AFR	LIT	SAA	
AFRLFLL	44			44
AFRLFPG	21			21
AFRLFPO	131			131
BAWEGKK			18	18
DLHEDDM		14		14
LIBLFPO			46	46
LITLFMN		56		56
Total	**196**	**70**	**64**	**330**

For flights with station stop-over time over 60 minutes the model of delay on departure is:

Dep Var: DELAYD N: 330 Multiple R: 0.915 Squared multiple R: 0.837
Adjusted squared multiple R: 0.834 Standard error of estimate: 3.791

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P
CONSTANT	4.969	0.439	0.000	.	11.332	0.000
BAWEGKK	-6.713	1.033	-0.164	0.792	-6.500	0.000
LITLFMN	-1.590	0.644	-0.064	0.745	-2.468	0.014
MOND	-1.299	0.509	-0.058	0.987	-2.556	0.011
HR14	-1.561	0.577	-0.066	0.847	-2.705	0.007
CHECK_IN	-0.041	0.005	-0.196	0.737	-7.478	0.000
ATRU_PAX_D	-0.014	0.002	-0.160	0.713	-6.016	0.000
DELAYA*DELAYA	0.005	0.000	0.874	0.979	38.482	0.000

When station stop-over time is long (over one hour), “load” on departure is still in the model with a negative coefficient. The negative sign of the coefficient is not modified whether the effect of “load” alone or interaction between “load” and station assistant is taken into account. When taking into account interaction (load x assistant), we notice that effects are significant for AFR and LIT, the ratio (-0.012 for AFR vs. –0.033 for LIT) being consistent with the relative numbers of passengers handled by those operators. When we do not take interaction into account, the coefficient for “load” is close to that of AFR alone (-0.014 vs. –0.012), which is due to the weight of AFR assistance (close to 60 %) in this sample. The effect of (SAA assistant) x (“load” on arrival) is not significant ($F < 1$) but we notice that its partial correlation to delay on departure is negative too. Introducing a sum of “load” on arrival and “load” on departure does not improve the model (R is unchanged).

Regarding “time scale” indicators, “Monday” and “Hour14” are entered. Coefficient is negative for “Hour14” which is an hour with a minimum regarding delays. The expected interaction between “Sunday” and “Winter”, due to ski charters, is far from being significant.

Check-in is still in the model with an expected negative coefficient (please refer to Section 3.3.2), close to -0.040. We notice that, in absolute value, the coefficient for check-in drops when station stop time increases (approximately –0.120 for station stop-over time up to 30 minutes, -0.080 for station stop-over time between 30 and 60 minutes, -0.040 for station stop-over time over 60 minutes).

Regarding terminal factors, baggage compartment security control and type of boarding are not significant but Hall is not far from significance in any case.

Effects of all aircraft traffic indicators (capacity, traffic on arrival, traffic on departure and local traffic) are not significant.

5.4 Night stop flights

Out of 159 records, 144 have scheduled hours between 06:00 and 08:59. These are likely to be most representative of night stop flights (flights departing, for instance, at 18:00 are very likely to stand for exceptional cases).

Airline	Scheduled hour (local time)			Total
	06	07	08	
AFRLFLL	28			28
AFRLFMN				0
AFRLFPG				0
AFRLFPO	4	22	12	38
BAWEGKK	12	9		21
DLHEDDF	2			2
DLHEDDM	7			7
KLMEHAM	2	2		4
LIBLFPO	10	5	1	16
LIBLFRS				0
LITLFMN		19		19
SABEBBR	9			9
Total	**74**	**57**	**13**	**144**

Five airline x destination (AFRLFLL, AFRLFPO, BAWEGKK, LIBLFPO and LITFLMN) have been tested. Amongst station assistants, PAA does not interfere with these airlines.

Airline	Station assistant				Total
	AFR	AVP	LIT	SAA	
AFRLFLL	28				28
AFRLFPO	38				38
BAWEGKK		9		12	21
LIBLFPO				16	16
LITFLMN			19		19
Total	**66**	**9**	**19**	**28**	**122**

Several trials were performed, including or not :

- interaction between assistants and "load" for passengers process ;
- delay on arrival.

Taking into account the interaction between assistant and actual passenger load does not really improve the model (R is not changed). Thus, the reference will not include interaction (station assistant x "load") because, on the one hand, multiple correlation and standard error of estimate are not worse and, on the other hand, it will be easier to handle for computations and future adjustments of the parameters. However, we must keep in mind that 2 station assistants (AFR and SAA) weigh 77 % of the sample and AFR alone 54 %.

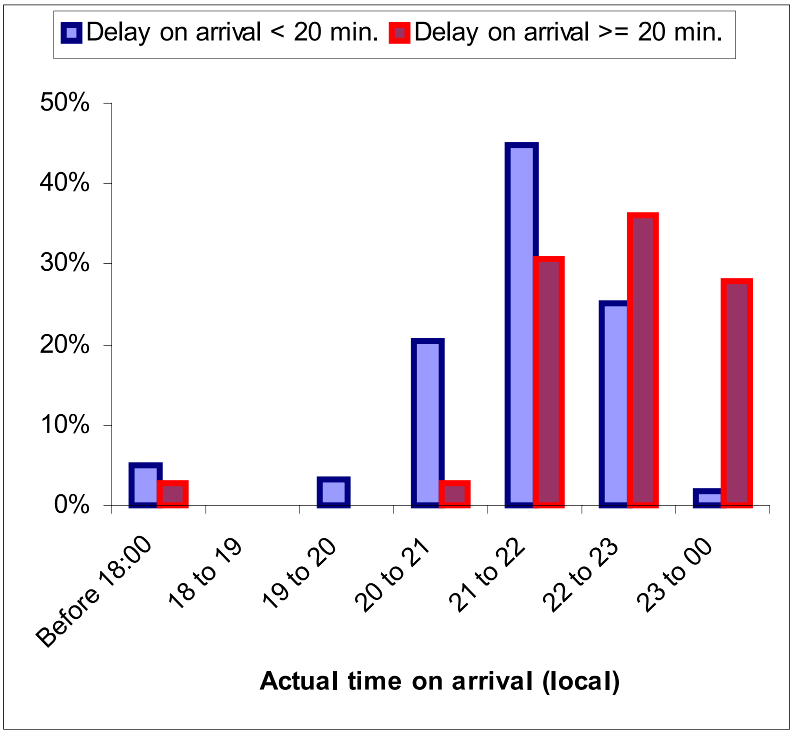
Dep Var: DELAYD N: 122 Multiple R: 0.587 Squared multiple R: 0.345
Adjusted squared multiple R: 0.311 Standard error of estimate: 5.424

Effect	Coefficient	Std Error	Std Coef	Tolerance	T	P(2 Tail)
CONSTANT	3.567	0.677	0.000	.	5.272	0.000
DELAYA	0.057	0.022	0.199	0.931	2.547	0.012
LIBLFPO	10.307	1.873	0.535	0.603	5.503	0.000
THID	-3.913	1.906	-0.157	0.971	-2.053	0.042
CHECK_IN	-0.057	0.011	-0.532	0.583	-5.380	0.000
PAX_ARR	0.012	0.004	0.260	0.832	3.140	0.002
ATRU_PAX_A	-0.031	0.011	-0.222	0.858	-2.730	0.007

All other effects are far from significance.

Surprisingly, models including delay on arrival (like the reference model above) are better. If we do not take delay on arrival into account, adjusted squared multiple R drops from 0.311 to 0.235. The coefficient for DELAYA (delay on arrival, +0.057) suggests that delay on departure increases by 1 minute when the delay on arrival (on the day before) increases by 20 minutes. The graph below shows that flights with a delay on arrival by 20 minutes or more ([14]) are on blocks later in the evening, close to 30 % being on blocks later than 11 p.m. local time. It is then very likely that the "delay on arrival" effect has something to do with aircraft preparation or crew availability.

([14]) Amongst flights departing on the next day, which are considered here.



The coefficient for Check-in is close to that we observed for flights with long station stop-over time (more than 60 minutes).

Once more, an indicator for the assistant load (here, for passengers on arrival) appears with a negative coefficient. This point will be discussed below. The total number of passengers on arrival bears a positive coefficient, which was expected. On the one hand, we assumed that increasing flows would result in increasing delays. On the other hand, the major direction, early in the morning, is departure. Flights on departure increasingly interact with flights on arrival and the positive correlation between delay on departure and the number of passengers on arrival probably accounts for this interaction.

6. Performances of the numerical models

6.1 Non-regulated flights

Results for non-regulated flights are detailed below. As discussed above, we have four different models :

- night stop flights ;
- otherwise, when station stop-over time is up to 30 minutes ;
- when station stop-over time is between 30 and 60 minutes ;
- when station stop-over time is more than 60 minutes.

In each case, the sections here below presents two tables; the first table gives the statistical parameters of the model, the second table gives results of a simulation performed on a (slightly) broader sample, including flights initially discarded for the computation of the model. Simulations are based on the standard error of estimate and on the coefficients listed in the overview of the model (next section) . We applied a rule of common sense : when delay on arrival is negative, its quadratic effect is considered to be zero.

6.1.1 Station stop-over times up to 30 minutes

Multiple R: 0.894 Squared multiple R: 0.799 Adjusted squared multiple R: 0.788 Standard error of estimate: 4.696 minutes

All flights, including CRXLSZM, DLHEDDF and BAWEGKK flights and all flights scheduled before 08:00 and after 22:00 local time were discarded for the computation of the model.

Number of flights	156
Number of flights included in the computation of the model	143
Average deviation to the predicted value	- 1.4 minute
SD of the deviation to the predicted value	9.0 minute
Average half-width of the range of predicted values (*)	9.4 minute
% of actual delays in the range of predicted values (*)	89 %

(*) 2 * SE of estimate

6.1.2 Station stop-over times between 30 and 60 minutes

Multiple R: 0.941 Squared multiple R: 0.885 Adjusted squared multiple R: 0.882 Standard error of estimate: 5.524 minutes

All flights, including CRXLSZM, DLHEDDF and LIBLFMK flights and all flights scheduled before 08:00 and after 22:00 local time were discarded for the computation of the model.

Number of flights	746
Number of flights included in the computation of the model	728
Average deviation to the predicted value	- 0.3 minute
SD of the deviation to the predicted value	6.1 minute
Average half-width of the range of predicted values (*)	11.0 minute
% of actual delays in the range of predicted values (*)	95 %

(*) 2 * SE of estimate

6.1.3 Station stop-over times over 60 minutes (on the same day)

Out of two possible models, our reference model will be that without interaction ("load" x assistant). Multiple R is not deteriorated and parameters will be easier to compute and process.

Multiple R: 0.915
Squared multiple R: 0.837
Adjusted squared multiple R: 0.834
Standard error of estimate: 3.791 minutes

All flights, including CRXLSZM, DLHEDDF, LIBLFMK, LIBLFRS and AFRLFMN flights and all flights scheduled before 08:00 and after 22:00 local time were discarded for the computation of the model. (The difference was only 10 flights).

Number of flights	340
Number of flights included in the computation of the model	330
Average deviation to the predicted value	- 0.3 minute
SD of the deviation to the predicted value	4.7 minute
Average half-width of the range of predicted values (*)	7.6 minute
% of actual delays in the range of predicted values (*)	94 %

(*) 2 * SE of estimate

6.1.4 Night stop flights

Multiple R: 0.587
Squared multiple R: 0.345
Adjusted squared multiple R: 0.311
Standard error of estimate: 5.424

All flights (whatever the airline and the scheduled hour), while only AFRLFLL, AFRLFPO, BAWEGKK, LIBLFPO and LITLFMN flights scheduled between 06:00 and 08:59 local time had been taken into account.

Number of flights	159
Number of flights included in the computation of the model	122
Average deviation to the predicted value	- 0.4 minute
SD of the deviation to the predicted value	5.8 minute
Average half-width of the range of predicted values (*)	10.8 minute
% of actual delays in the range of predicted values (*)	94 %

(*) 2 * SE of estimate

6.2 Regulated flights

Since the statistical parameters of the models were based on non-regulated flights, we only carried out simulations for regulated flights. The ATC delay (computed as the difference between scheduled time and the slot taking a standard taxiing time into account) is considered to be an input.

For each flight, we compute a non-ATC expected delay as above. We consider the flight is not able to depart before the lower edge of the range for non-ATC delay (based on 2 S.E. of estimate), even if the ATC-delay is shorter. On the other hand, if the ATC-delay is above the upper edge of the range for non-ATC delay, we consider it to be the restricting factor i.e. the overall delay may increase up to the value of ATC-delay.

Considering ATC-delay to be the lower edge of the predicted overall delay when it is above the lower edge of the range for non-ATC delay would result in narrower ranges of predicted values. However, further analysis (not detailed here) showed that the overall delay may well drop very much under the value of the ATC-delay and the quality of the prediction (misclassified cases) is then poorer. Thus, we believed it to be more reasonable to consider in any case the lower edge of the range for non-ATC delay to be the absolute lower edge of the predicted overall delay.

In summary, overall delay is expected between the lower edge of the non-ATC delay and the higher value amongst ATC-delay and the upper edge of the non-ATC delay. The table below shows the results of the simulations.

Parameters	Rotation on two different days	Rotation on the same day / Stop time		
		<=30 min.	30-60 min.	>60 min.
Number of cases	409	131	729	299
Average overall delay	10.0	14.6	17.2	12.6
ATC-delay	15.2	20.5	22.7	17.7
% of actual delays within the range of predicted values including ATC-delay *	91%	93%	95%	92%
Half-range for non-ATC delay (2 S.E. of estimate)	10.8	9.4	11.0	7.6
% flights with ATC-delay > upper edge of non-ATC	40%	66%	45%	50%
% of actual delays in the range of non-ATC predicted values when ATC-delay is not constraining**	91%	84%	93%	91%

* The upper edge of predicted values is either the ATC-delay or the upper edge of predicted non-ATC delays

** i.e. ATC-delay is below the upper edge of non-ATC predicted values

In any case, the prediction is correct for 90 to 95 % flights. ATC-delay is not the constraining factor of the overall delay for 35 to 50 % regulated flights. In those cases, the prediction is correct for 85 to 95 % flights, which is a reasonable cross-validation of the numerical models since they were computed on the basis of independent data sets. This rate of correct prediction is achieved, as previously shown, with a range of approximately ± 10 minutes around the predicted value.

7. Overview of the model and discussion

7.1 Overview of the general model / process

Before discussing the most noticeable contributions of this study, it may be useful to recall the successive stages of the process, which should also be the elements of a complete operational model, and the numerical form of the partial models as shown above.

Our aim was to analyse the development of delays on departure under the dependency of some structural and functional factors that could be given a value directly or indirectly (through a special computation) on the basis of routine archives ([15]). We wished to focus especially on the sensitivity of delays to variations of the local traffic (aircraft and passengers).

The initial data set included some 3,146 flights on departure sampled out of 6 weeks during the first six-month period of 2001. The figure below presents the stages of the process.

Firstly we considered it necessary to discard "exceptional events", identified through a restricted number of delay IATA codes. We assumed that in such cases, as for instance aircraft failure, the delay on departure was not predictable, at least on the basis of the criterion we intended to give a value to as explanatory variables. These cases represent 4 % of the total flights processed.

Secondly, we had to identify and discard cases labelled as "non-standard turnarounds" ([16]) because, when an airline tactically decides to allocate a departure to an aircraft that is not the usual aircraft dedicated to this scheduled flight ([17]), the relationship of delay on departure against delay on arrival is broken. Indeed, non-standard turnarounds give evidence that the usual aircraft is not available, either because it is out of order or because it is greatly delayed on arrival. Non-standard turnarounds represent 1 % of the total flights processed.

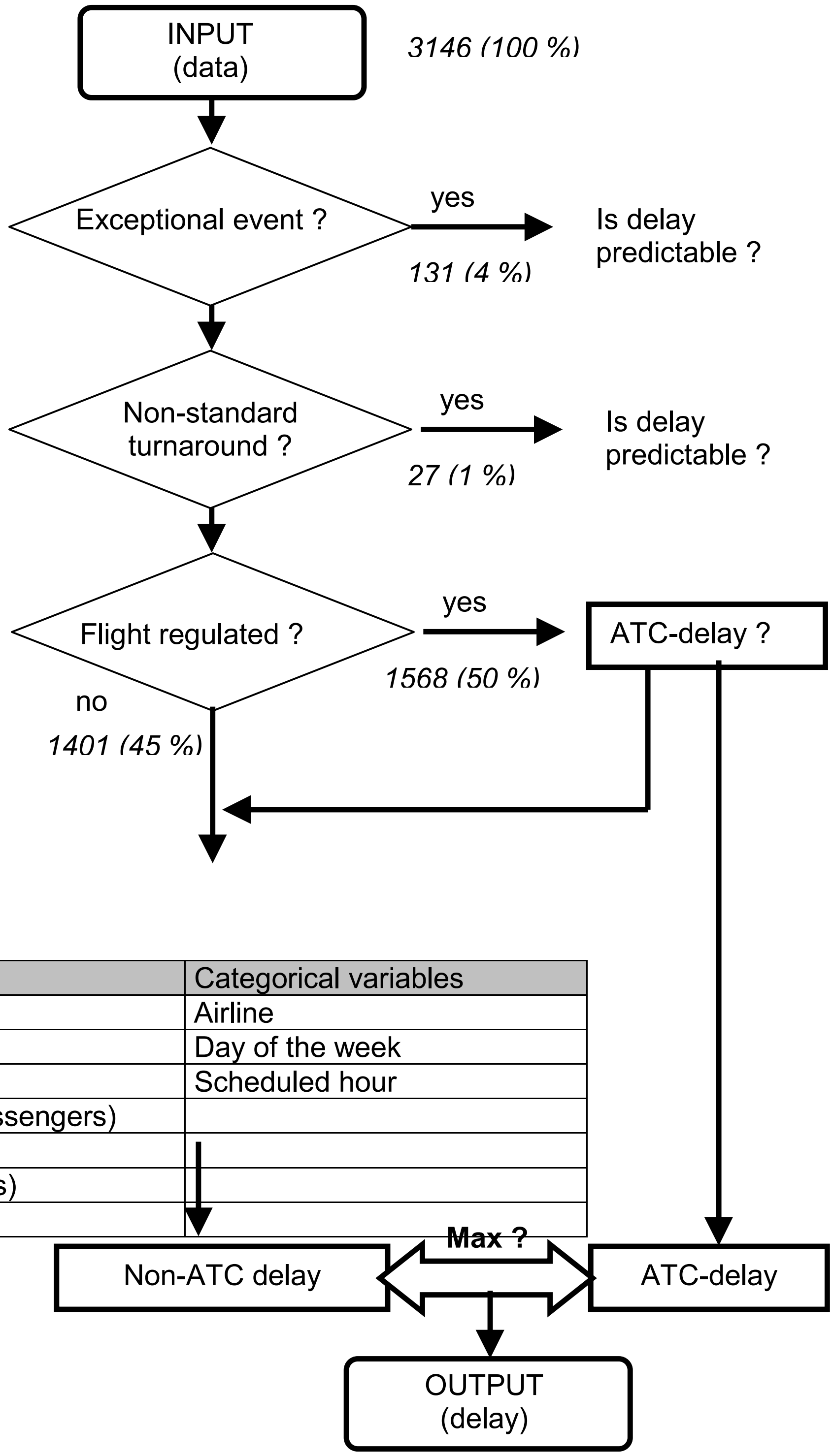
Otherwise, some 20 flights were discarded for various reasons, including identified shifts in EOBT. One of our initial aims was to assess situations where an airline declares to AFTM a tactical change in its scheduled time of departure (shifts EOBT), due to a non-ATC expected delay. We were interested in possible consequences in ATC-delay, the new EOBT being likely to support a regulation. The number of such cases found in the FPL archive file was too low to be processed.

In the third stage, the file of remaining flights was divided into two, depending on the *existence of a regulation*. We then had 50 % regulated flights and 45 % non-regulated flights out of the initial sample. It is important to underline that *a flight submitted to a regulation (thus having a slot) may well have a very short ATC-delay*.

([15]) Even when requiring a vertical matching of data from various operators like airport management, global ATC or airlines.
([16]) In fact, for further use of the model, the important point is to know for each airline what is (are) the standard turnaround(s). This is easily ascertained.
([17]) Setting up of an empty plane or any other commercial flight.

Overview of the general model / process

(italics give indication of the number of cases)



Quantitative variables	Categorical variables
Delay on arrival	Airline
Stop time	Day of the week
Capacity	Scheduled hour
Station assistant load (passengers)	
Check-in	
Terminal load (passengers)	
ATC load (aircraft)	

In fact, each segment was broken in four, depending on the station stop-over time. This point will be discussed below (*see Discussion*). Each sub-segment is associated with a partial numerical model depicting the relationship of delays on departure to explanatory variables. Before entering the discussion, the main features of the segments and the numerical models are summed up in the next tables.

Turnaround	Performed on the same day			Performed on 2 different days
Stop time	≤ 30 min.	30 – 60 min.	> 60 min.	
Model	NR0 0030	NR0 3060	NR0 60PP	NR1
Non-regulated flights	N = 156 DLA = 0.2 min. DLD = 5.0 min.	N = 746 DLA = 5.8 min. DLD = 8.3 min.	N = 340 DLA = 6.9 min. DLD = 3.7 min.	N = 159 DLA = 9.0 min. DLD = 5.2 min.
Regulated flights	N = 131 DLA = 0.0 min. DLD = 14.6 min. ATC = 20.5 min.	N =729 DLA = 10.0 min. DLD = 17.2 min. ATC = 22.7 min.	N = 299 DLA = 11.4 min. DLD = 12.6 min. ATC = 17.7 min.	N = 409 DLA = 12.1 min. DLD = 10.0 min. ATC = 15.2 min.

For regulated flights, it is noticeable that ATC-delay may be above the actual overall delay. On the one hand, the ATC-delay is somewhat conventional since we computed it as the difference between the scheduled block time and block time to achieve the slot based on a standard taxi time of 5 minutes. On the other hand, we observe that a number of flights actually leave blocks far before the block time to achieve the lower edge of the slot window. Data available do not allow us to decide whether these flights actually take off outside (before) the slot window or if the slot window is achieved waiting on taxiways.

Depending on the type of turnaround and on station stop-over time, the same numerical model is applied to non-regulated and to regulated flights. Regarding regulated flights, we only have an extra operation to compute : test if the ATC-delay is above the upper edge of the range of predicted values out of the numerical model. If this is the case, the overall delay is expected between the lower edge of the range of predicted values for the non-ATC delay and the ATC delay itself. If not, the overall delay is expected in the range of predicted values for the non-ATC delay.

Numerical models are presented here below where :

- NR1 is the model for night stop flights ;
- NR0 0030 is the model for flights with station stop-over time up to 30 minutes ;
- NR0 3060 is the model for flights with station stop-over time between 30 and 60 minutes ;
- NR0 60PP is the model for flights with station stop-over time more than 60 minutes.

Parameters	NR0 0030	NR0 3060	NR0 60PP	NR1
CONSTANT	32.592	39.399	4.969	3.567
Delay on arrival and stop time				
DELAYA	0.406	0.564		0.057
DELAYA*DELAYA	0.011	0.003	0.005	
STOP TIME	-0.842	-0.448		(Not tested)
Runway and aircraft traffic				
CAPA		-14.813		
TFC_DEP		-0.340		
Load at check-in for the flight				
CHECK_IN (*)	-0.120	-0.081	-0.041	-0.057
Total passengers load on the station assistant				
ATRU_PAX_A				-0.031
ATRU_PAX_D		-0.007	-0.014	
Total passengers load in terminal				
PAX_DEP		0.003		
PAX_ARR				0.012
Airline				
AFRLFLL		-5.206		
AFRLFMN		5.540		
AFRLFPG		4.498		
BAWEGKK		-4.532	-6.713	
LIBLFJL		10.647		
LIBLFMK	-7.920			
LIBLFPO		3.387		10.307
LITLFMN			-1.590	
SABEBBR	4.730			
Day of the week				
MOND			-1.299	
THID				-3.913
SATD	10.718	2.511		
Scheduled hour (local time)				
HR13		-2.829		
HR14			-1.561	
HR20		2.511		

(*) Due to initial definition, load at check-in is high when CHECK_IN is low (there is a lack of minutes to check-in the actual number of passengers). See Section 3.3.2 and below.

7.2 Discussion

Initially, we did not expect very much from this study as a predictive, operational tool. The heuristic side of it was privileged, i.e. corroboration of hypothesis regarding to factors affecting delays and improvement of our knowledge about the development of delays at a local level.

However, results show that the predictive value is corrrect and we are thus planning to discuss applications of the model.

7.2.1 Heuristic point of view

a) Station stop-over time

Station stop-over time was expected to have a strong impact on delays on departure, and indeed this is the case. The average delay on departure does not seem to be significantly different depending on station stop-over time but, in fact, laws explaining the increase in delays on departure are drastically different depending on station stop-over time.

Of course, it was expected that response of delay on departure as against variations of delay on arrival would differ depending on station stop-over time. But one of the most noticeable results is to give a value to the differences in response and improve our knowledge about the underlying mechanisms.

b) Delay on arrival

Depending on station stop-over time, the part of the models regarding delay on arrival is detailed below :

		Effect on DLD of :	
Station stop-over time	Model (part)	-5 min. SST	+10 min. DLA
<= 30 min.	0.406 DLA + 0.011 DLA * DLA – 0.842 SST	+ 4 min.	+ 5.060
30-60 min.	0.564 DLA + 0.003 DLA * DLA – 0.448 SST	+ 2 min.	+ 5.940
> 60 min. (same day)	0.005 DLA * DLA	-	+ 0.500
Night stop	0.057 DLA	-	+ 0.570

DLD : delay on departure DLA : delay on arrival SST : station stop-over time

We have discovered by chance there was still an effect of the delay on arrival in residuals from the regression of delay on departure against delay on arrival. This quadratic effect, which should not be applied to negative delays on arrival when the model is used for operational purpose, adds to the simple (linear) effect.

The simple effect may be seen as a "mechanical" effect **:** minutes "missing" on arrival (because the plane was late) are still "missing" on departure (in order to achieve the scheduled hour). In fact, considering coefficients above, we could say that, ***for flights with station stop-over time of up to 60 minutes, 2 minutes missing on arrival result in 1 minute missing on departure***. It is noticeable that, when station stop-over time is over 60 minutes, there is no linear effect of the delay on departure. We could say that, ***when station stop-over time is long, minutes missing on arrival are not likely to be missing on departure, at least for usual delays*** ([18]). Surprisingly, we find a (weak) linear effect of the delay on arrival for night stop flights : an increase by 20 minutes in delay on arrival would result in an increase by 1 minute in the delay on departure. Regarding flights usually arriving in the evening and departing early in the morning, we have shown that those delayed (on arrival) by 20 minutes or more are on blocks significantly later in the night. Thus, we may assume that minutes are missing in the morning because of the transfer of some maintenance operations due to lack of staff during the night or (and that would be consistent with a linear effect) in order to complete the flight crew standard rest time.

The quadratic effect accounts for the differential effect of very long delays on arrival, the length of delays here being relative to the station stop-over time : when station stop-over time is up to 30 minutes only, a delay on arrival by 20 minutes should be considered to be very long : the quadratic effect adds a 4 minutes component to the linear effect. In contrast, when station stop-over time is long, the delay on departure is not significantly proportional to the delay on arrival. Given the coefficient for the quadratic effect (0.005), we can say that if the delay on arrival is under 15 minutes, the flight will not be delayed on departure. But a 50 minute delay on arrival will result in 12 minutes delay on departure. ***A very close interpretation of the quadratic effect is that it accounts for organisational and operational disruptions caused by the delay on arrival, disruptions being increasingly significant as delay on arrival increases.*** For instance, in the case of long station stop-over time, you generally have enough time to complete the turnaround but, if the delay on arrival is very long, you nevertheless have a significant disruption in the process.

c) Check-in (or relative load of the aircraft)

The CHECK_IN indicator was defined as (See Section 3.3.2) :

(Standard number of seats – Actual number of passengers) / Rate at check-in * 60

Standard number of seats and rate at check-in are standard values for a given airline x destination. Rate at check-in is the average number of passengers checked-in in one hour for a given airline x destination. It is routinely adjusted every year.

We initially wished to introduce into the model a measure of the "lack of minutes" for checking-in the actual number of passengers. An undesirable consequence of that definition is that correlation is in fact negative with the actual load.

We think that ***the CHECK_IN indicator is very relevant***, for two reasons :

- Its effect is significant in the different partial models. Delay on arrival is the only other indicator having this property.

([18]) Very unusual and long delays are very likely to fall into cancelled flights (when due to the delay on arrival), rejected delay IATA codes or non-standard turnaround categories and be under-rated in our sample.

- Its coefficient is decreasing depending on station stop-over time and is very similar when station stop-over time is over 60 minutes (-0.041) and for night stop flights (-0.057).

For non-regulated flights with a station stop-over time of 30 to 60 minutes, which are in the majority but do not bear the strongest correlation with CHECK_IN, the average CHECK_IN is close to 40 minutes i.e. there is on average a surplus of 40 minutes in order to check-in the actual number of passengers. If all of the flights were loaded at their maximum capacity, then delay on departure would increase from 8 to 11 minutes ([19]).

Station assistants say that, in their opinion, the boarding process is more constraining than the check-in process. We are aware that CHECK_IN is not a direct measure of the actual load at check-in. But, the fact that we have homogenous correlations with delays even though CHECK_IN includes an average rate at check-in, which may vary two-fold between airline x destination, enhances the idea that this indicator actually measures a load at check-in. However, if the rate of passengers at boarding was in the same proportion to the rate at check-in whatever the airline x destination, the boarding process could be implicated, alone or altogether with the check-in process.

d) Passenger load in terminal

A previous study had shown there could be a positive correlation between delay on departure and the total number of passengers in flights departing within the scheduled hour. However, this result was obtained under very restrictive conditions.

We assessed the "total passenger load in terminal" as the total number of passengers in flights actually arriving or departing within a number of minutes before the scheduled time : 45 minutes for the "departure" load, 60 minutes for the "arrival" load. ***We intended to have a measure of interactions and conflicts due to the number of passengers in terminal or, to some extent, of the terminal congestion***.

The effect of the load on departure is significant for flights with station stop-over time between 30 and 60 minutes. It is approximately of 1 more minute in delay for 300 more passengers on departure. It is thus not very significant but consistent with the previous result mentioned above, deduced from an independent data set.

Not surprisingly, there is a significant effect of the load on arrival for night stop flights. Most of these flights are scheduled early in the morning. The earliest departures do not face any traffic on arrival at a moment when the level of traffic (aircraft and passengers) is low. Conversely, when departing later, we have a sharp increase in traffic on arrival.

In conclusion, we may say that ***terminal congestion somehow adds a small positive component to the average delay on departure***.

([19]) It should be mentioned however that we did not take into account, for that simulation, the correlative increases of the terminal load (which would increase the delay) and of the total load on station assistants (which would reduce it, see below).

e) Capacity

The CAPA indicator is a conventional measure of restrictions to runway capacity. Causes may be meteorological or due to repairs for instance. It is conventional because we collected information about events and applied ratios detailed in the local ATC instructions, depending on the type of event. CAPA may range from 1 (maximum capacity) down to 0 (closure of the airport). Unfortunately, we did not have in our sample events severely affecting capacity and CAPA actually ranges between 0.7 and 1.0.
Like some other flow indicators, capacity is not in all of the partial models but only for flights with station stop-over time between 30 and 60 minutes. However, in that case, the ***effect of capacity may be great*** since its coefficient is about –15. On average, CAPA is very close to 1. If we reduce it homogenously down to 0.7 ([20]), then the average predicted delay increases from 8 to 12 minutes.

f) Total passenger load on the station assistant and aircraft traffic

These indicators are associated here because, like "terminal" load or capacity, they do not appear in all of the partial models and, moreover, they bear unexpected negative coefficients. Statistical outputs have been carefully checked : when non-significant, most partial correlations are however negative. Simple correlations between aircraft or passengers handled by station assistants and delay on departure have been computed. If considering the load for passengers on departure, they are all negative except for one station assistant.

This result suggests first that local ATC and most station assistants have adequate staff and equipment to cope with traffic. We think that, when significant, those indicators give ***a measure of the steady flow of traffic***. The consequence is a negative correction to the increase in delay generated by the correlated increase in "check-in" (for one particular flight) and in terminal congestion.

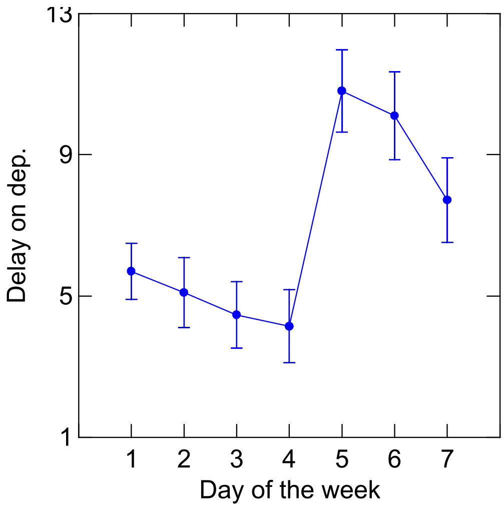
g) Airline x destination, day of the week and scheduled hour

We gave importance to an explanation of delays regarding functional indicators and, especially, to flows (traffic level, capacity). However, we expected that some qualitative factors would affect delays, as the airline x destination.

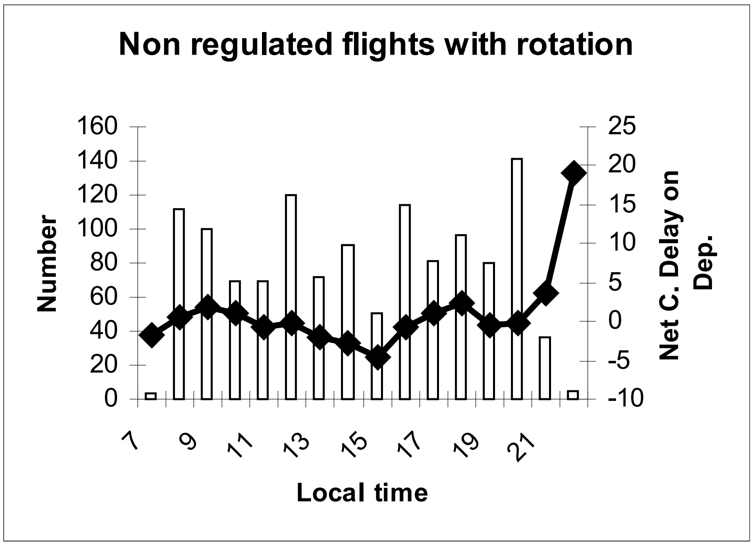
An in-depth analysis could help to identify quantitative descriptors (e.g. related to staff, aircraft, etc.) of mechanisms underlying differences between airline x destination, but we are not interested in that aspect and will consider the airline x destination as a "black box". Nine airline x destination out of 18 in the sample bear a significant effect, i.e. there is a significant correction to apply to the delay on departure predicted otherwise. ***The correction to be applied to the predicted delay on departure ranges between –7.9 and +10.6 minutes depending on the airline***. This is a fair correction compared to the respective effects of quantitative variables listed above.
Regarding the day of the week and the scheduled hour, we did not want possible effect to be correlated with traffic and capacity i.e. be redundant with quantitative variables depicting traffic and capacity.

([20]) We do not advise extrapolations.

This result is achieved since partial models allocate a negative correction to Monday and Thursday, but a positive correction to Saturday. ***Corrections range between –4 and +3 minutes (21)***. This is consistent with the analysis of the "day of the week" factor alone, which shows that ***average delay on departure is longer at week-ends*** (starting on Friday evening). This is obviously not a "flow" indirect effect since traffic is at its minimum at weekends. We think difference between days are thus the consequence of structural differences (in type of demand, staff, availability of resources, etc.) and have something to do with high job-related proportion in Toulouse Blagnac traffic.



Corrections for the scheduled hour range between –3 minutes (at 13:00 local time) and +3 minutes (at 20:00 local time). These corrections are consistent with the within-day variations of delay on departure (see graph below). It is noticeable that, on the one hand, in so far as scheduled hours have a significant effect, the delay on departure is positively correlated with the level of traffic. On the other hand, scheduled hours which have a significant effect are close to meal times. Thus, a structural effect remains possible. This should be analysed in depth.



Net C. delay on departure *stands for the residuals from the regression of delay on departure against delay on arrival.*

(21)With the noticeable exception of the partial model for very short station stop-over times, but some results, like this one, could be strongly influenced by some special cases.

7.2.2 Applications of the model

Applications of the model were not initially our major concern because we did not know whether the quality of prediction would be sufficient. Results show that 95 % of non-ATC delays are correctly predicted in a range of ± 10 minutes. On the other hand, we have shown that, for regulated flights, 95 % overall delays are predictable, using the same partial models for the non-ATC part of the overall delay and the ATC-delay itself as an input.

We are planning to make several applications all based on simulations. The method may be simple, e.g. based on an Excel spreadsheet, but the model might be included in software with input either being data for a single flight or data for a batch of flights. Possibility to process batches of flights would be of interest for complex simulations. However, this point is not included in the present project.

a) Heuristic

The first type of application is in heuristic simulations like : ***what about the average delay on departure from Toulouse Blagnac if all flights on arrival were on time ?*** We show that the average delay on departure would still be 3.1 minutes vs. an actual delay by 6.5 minutes for non-regulated flights. This means that delay on arrival is not, by any means, the only factor significantly affecting the non-ATC part of delays and that local factors are operating.

b) Planning of operations that can affect punctuality

Local instances, like ATC and airport management, are interested in forecast tools ***when planning some operations affecting traffic, like repairs***. We have shown above that, if we homogenously reduce runway capacity by 1/3, then the average predicted delay increases from 8 to 12 minutes. It should be noticed that a reduction by 1/3 is moderately severe and close to that applied in the case of annual repairs for instance. But this reduction of capacity was applied to the whole sample, thus in average conditions regarding traffic and time. Of course, repairs are planned within low traffic periods.

Another application is related to analysing the ***consequences in delays of an increase in local traffic***. For instance, we have shown that, if all of the flights were loaded at their maximum capacity, then delay on departure would increase from 8 to 11 minutes ([22]). But this kind of application - to traffic - requires preparation because several indicators are correlated : you cannot change the “load” at check-in without adjusting the “terminal congestion”, the “load” on station assistants and the aircraft traffic consistently.

c) Short-term, operational management oriented

Aircraft management or station assistance might be interested in prediction for a special flight, for instance when it is known to be significantly delayed on arrival. For that purpose, standard estimates of some indicators included in the model should be provided.

([22]) Only considering non-regulated flights with a station stop time between 30 and 60 minutes, which are the most numerous.

8. Conclusion

Building a model of delays on departure from a stop-over point of view has proved to be successful.

First, from a heuristic point of view, we confirm several indications such as the prominent role of the station stop-over time and, of course, of the delay on arrival. But we also show that other local factors play an important role since delay would only be reduced by 50 % if all (non-regulated) flights on arrival were on time. Some of the local factors are structural (the airline, the scheduled hour) but variables related to traffic and capacity play a role, the most crucial being the relative load of the aircraft.

Moreover, the predictive value of the model has proved to be sufficient to allow an operational use as a planning tool.

A very important point is that we discarded cases when delay (according to the recorded cause) was not predictable (exceptional events, like aircraft failure) and did not analyse the ATC-part of the overall delay (the latter being considered as an input). ***One crucial application of the model is to show that we have a "low noise" generation of short non-ATC delays at the local level***, i.e. the local system including ATC, airport, airlines and station assistance.

If it was confirmed that a compensation of those short non-ATC delays is not possible through the average flight duration – we should compare overall delays on arrival with overall delays on departure from the opposite airport – then the "low noise" generation of short delays at the local level could play an important part in the general propagation of delays throughout the whole system.