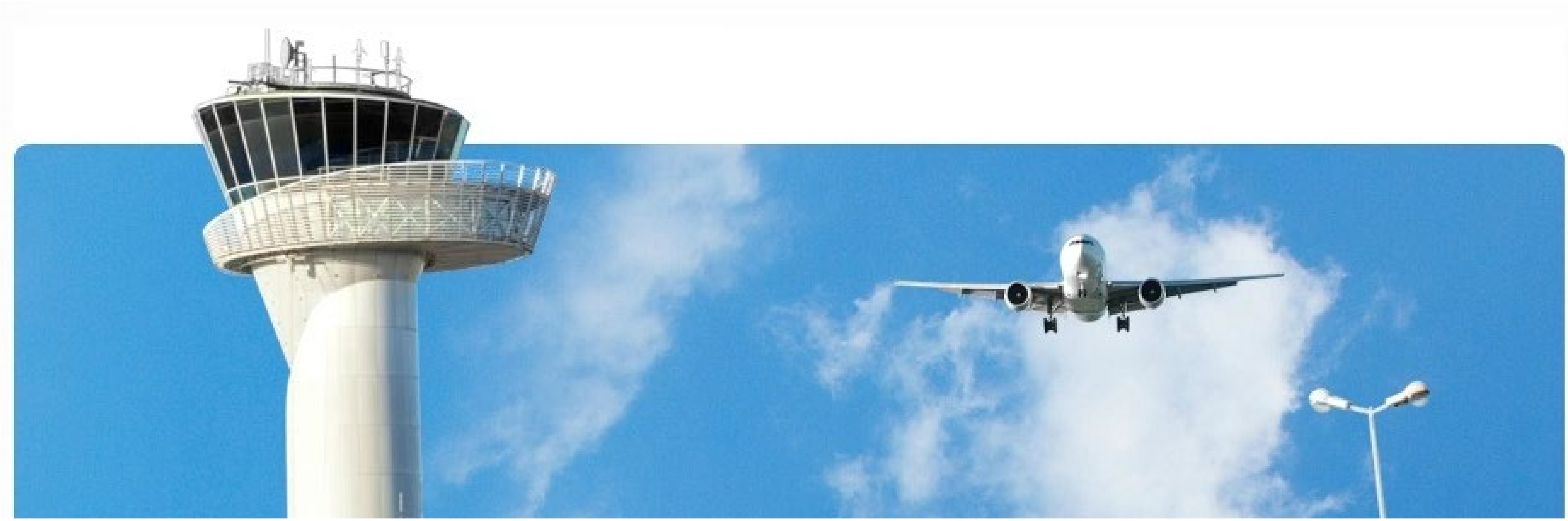
Models for Air Traffic Management



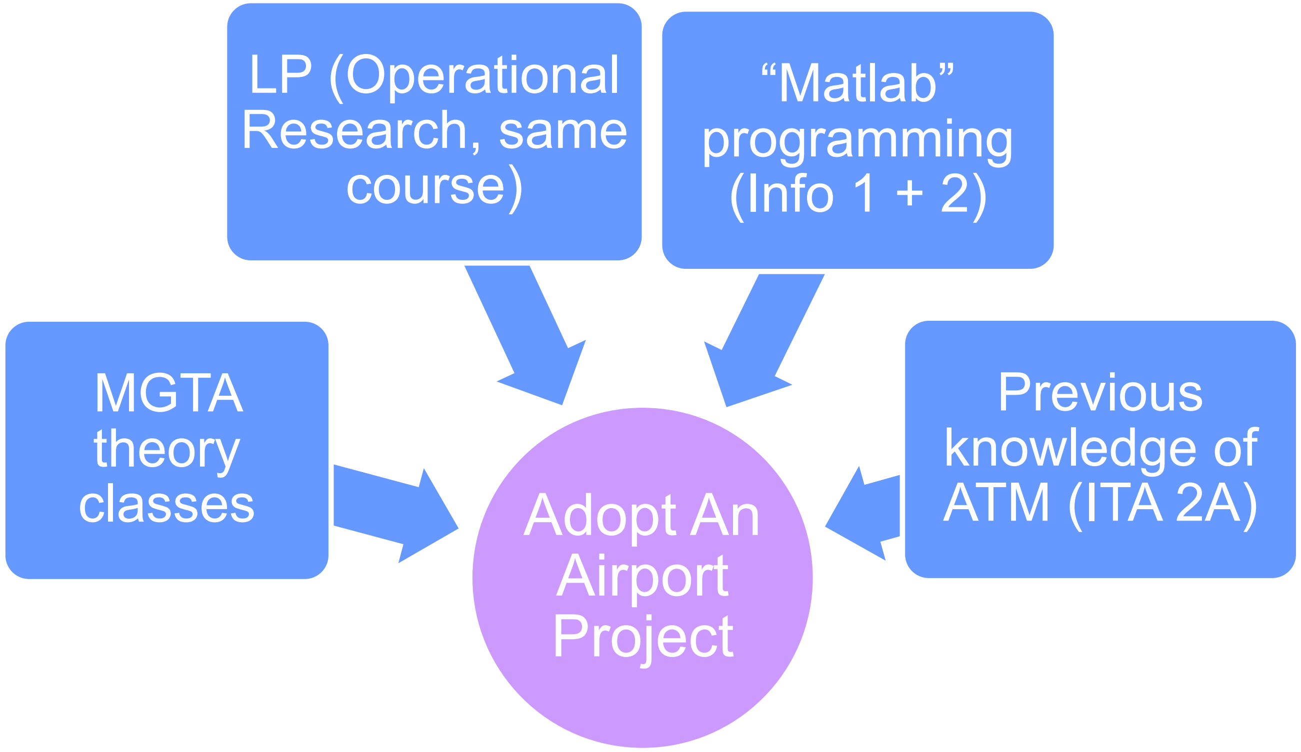
Adopt an Airport Project

09/09/2024

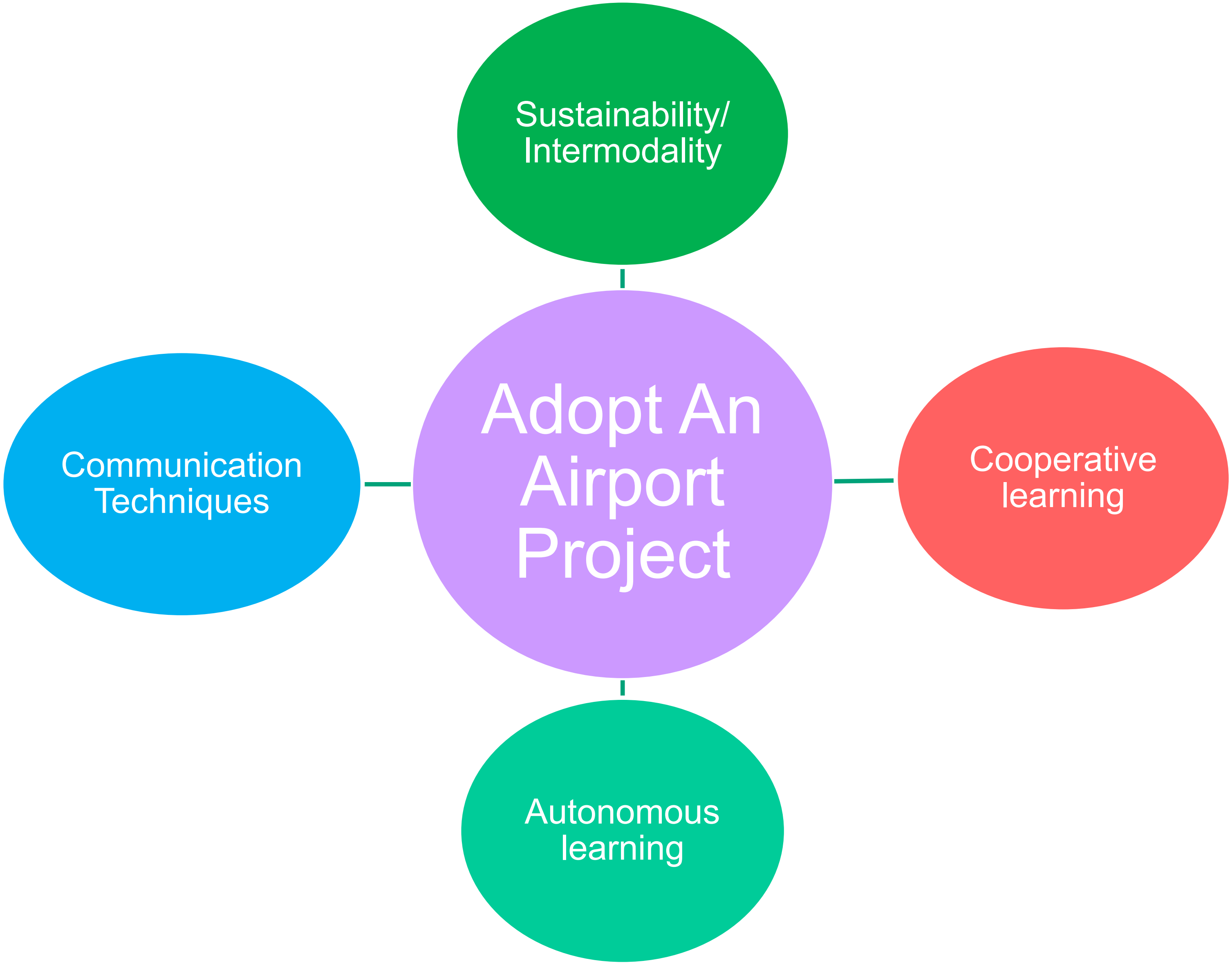
Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels
UNIVERSITAT POLITÈCNICA DE CATALUNYA

Project objective

Given an chosen (adopted) European airport where traffic regulation is applied, apply different ATFM methods to it and study relevant metrics (number of flights affected, mean delay per flight, air vs ground delay, total delay, standard deviation of delay, extra cost, emissions of delay, etc.)



Project objective



Project index

- **WP1**: Generate data and define regulation on your airport
- **WP2**: Apply a GDP
- **WP3**: Apply a GHP
- **WP4**: Consider intermodality
- **WP5**: Analyze results, compare and evaluate methods, and conclude

Project planning

Weeks:	1	2	3	4	5	6	7	8	9	10
WP1 (Traffic+Reg)										
WP2 (GDP)										
1p progress report										
WP3 (GHP)										
WP4 (InterModal)										
WP5										
Oral test Deliver paper										

Project planning

1 page progress report (13/10)

One page progress report giving main results of delays (KPIs) for the regulation defined, and the GDP solution

Oral test (week 10: 19/11 and 21/11)

Oral test (in English) with short questions on the tasks you were involved in (contribution of group members will be delivered shortly before)

Deliverable: report due on November 24th (10 pages max.)

Two templates are available (Word and Latex), make sure to respect basic rules of format (Figures and Tables captions, references, etc.)

Continuous following of the work

Once a week, one member of the group will present to the professor the main results obtained by the group during the past week as well as their doubts. This group *leader/spoke(wo)man* should be the WP responsible (and thus change along the project)

From week 5, both MGTA classes will be dedicated to the project and longer consults and interviews will be possible.

References

1 class session (around week 7) will be dedicated to talk about references, databases, AI, correct use of citations to avoid plagiarism, etc.

Project planning

Evaluation (project counts for 36% of MGTA total grade)

Weekly updates, participation to classes, stick to planning:	10%
One page progress report	5%
Individual oral test:	15%
Final report	70%

Accuracy and presentation of results, justification of choices made, quality of references used, originality of the results (graphs, chosen metrics, etc.) and **above all analysis of the results** presented will be (between others) some of the evaluation criteria

General advice

- be flexible: some data may change along the project, you may realize the regulation is not “constraining enough” and there is hardly any delay, or you may need to add an hour of study, or change the capacity, etc. Program in such a way (**use variables**!) that it will be no problem if you have to change a parameter and re-apply all methods
- justify your choices: the report should focus on the choice you had to make, or how you solved some challenges, not on the obvious parts
- analysis: invert enough time on **interpretation of results / comparison of methods/conclusions**, this is where good part of the grade will go
- plan well: try to stick to the chronogram, and you will have a smooth end of the project

General advice

- Team work: divide well the work: you need to properly share tasks between group members so that you progress fast enough, at the end of the project you will need to deliver the contributions of each member (during the oral test, you will be evaluated on the tasks where you were more involved)

- use of Matlab for computation is recommended https://serveistic.upc.edu/ca/distsoft/el-servei/programari-per-a-estudiantsi-professors#section-4, but Python is also possible

- **AI/ChatGPT exist and can help, if you use it, comment with us how to correctly include the information provided**

General advice

+ we can also answer any doubt you will have → ask us!

We will not solve code problems during office hours (nor by email), but we will help you with conceptual problems.

WP.0: Form your group and send an email (to Adeline or David/Plamen) with group members and airport name

→ Before 16th of September 2024

WP.1: Generate data and define regulation on your airport

Project planning

Weeks:	1	2	3	4	5	6	7	8	9	10
WP1 (Traffic+Reg)										
WP2 (GDP)										
1p progress report										
WP3 (GHP)										
WP4 (InterModal)										
WP5										
Oral test Deliver paper										

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WP.1: Generate traffic data at your airport

You have been assigned an airport (FRA, AMS, CDG, LHR, MAD, MUC, BCN, LGW, FCO (Rome), ZRH), you need to generate its arrival traffic data and obtain its arrival capacities:

1. From the data provided, using either NEST (as you did in ITA), or the given Matlab or Python functions (parse_allft) to read the ALL_FT+ file (20160129.ALL_FT+), you will obtain a table including 24h of traffic (UTC) in Europe.
2. Filter the data to keep only the flights arriving at your chosen airport.
3. For each flight arriving at your airport you will thus directly have:
   a. its departure airport (ICAO code),
   b. its flight number,
   c. the airline code,
   d. the aircraft type,
   e. the scheduled times of departure and arrival (STD & STA), in format 'yyyymmddhhmmss' (UTC), convert them to your airport local time.

WP.1: Generate traffic data at your airport

4. For each flight arriving at your airport, you need to compute:

   a. the flight distance (it can be calculated from STD & STA to get the flight time and then applying an average speed),

   b. whether the flight is from outside ECAC (https://www.ecac-ceac.org/about-ecac/member-states), you can filter by the ICAO origin airport code (LF is France: within ECAC, UU is Russia: outside ECAC, etc.)

   c. aircraft category (obtained from aircraft models): use the new RECAT-EU categories to assign to each aircraft its category (between A and F), see for instance: https://www.eurocontrol.int/archive_download/all/node/9681 or https://www.easa.europa.eu/en/downloads/117238/en

   d. available seats (obtained from aircraft models or from aircraft category previously obtained): this will be needed in WP3

WP.1: Regulation definition

Study your airport arrival capacity: https://www.eurocontrol.int/publication/technical-note-airport-capacity-imbalance

a. Determine nominal (AAR) capacity from the EUROCONTROL document and set a reduced (PAAR) arrival capacity (consider for example very bad weather conditions that would greatly reduce the capacity)

b. Calculate the corresponding size of the time slots ***t.*** These slots will be used for computing regulations delays, they do not necessary correspond to ATFM slots.

You can choose to have integer or not slots, and you can have 1 or 2 flights by slot if you think this is needed.

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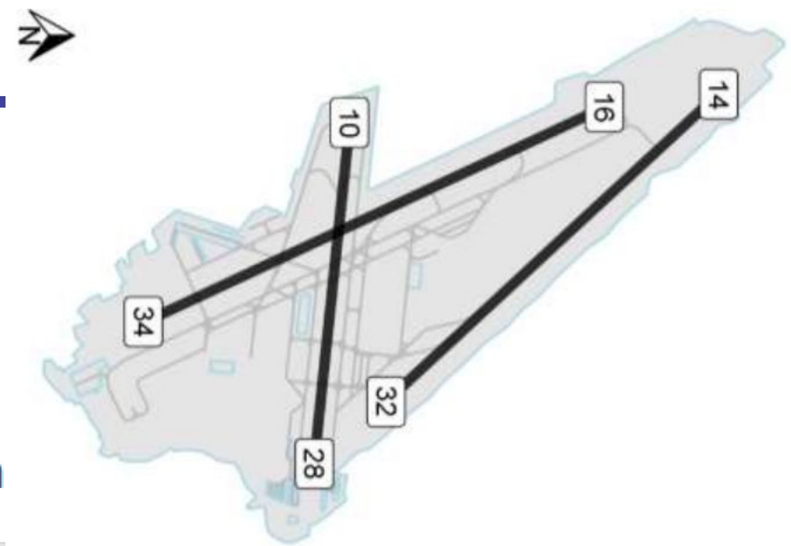
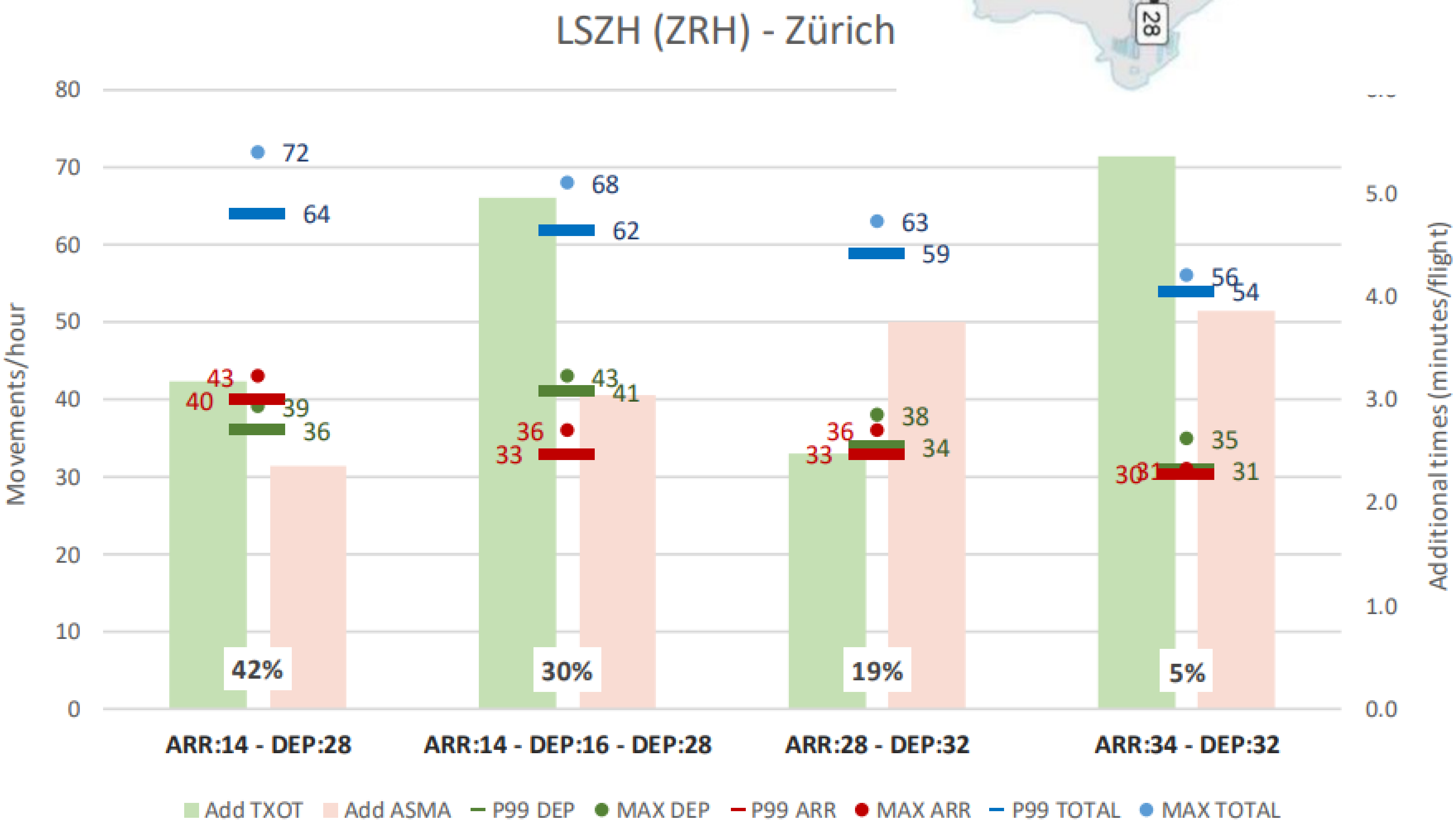
WP.1: Capacity study

From the [AIRPORT CAPACITY IMBALANCE STUDY, 2020]

ZRH example:





WP.1: Regulation definition

6. Define the hypothesis of your regulation, namely:

   - **file time** (`Hfile`): when the regulation is set and the regulated slots are sent to the airline
   - **starting time of reduced capacity** (`Hstart`),
   - **end time of reduced capacity** (`Hend`)

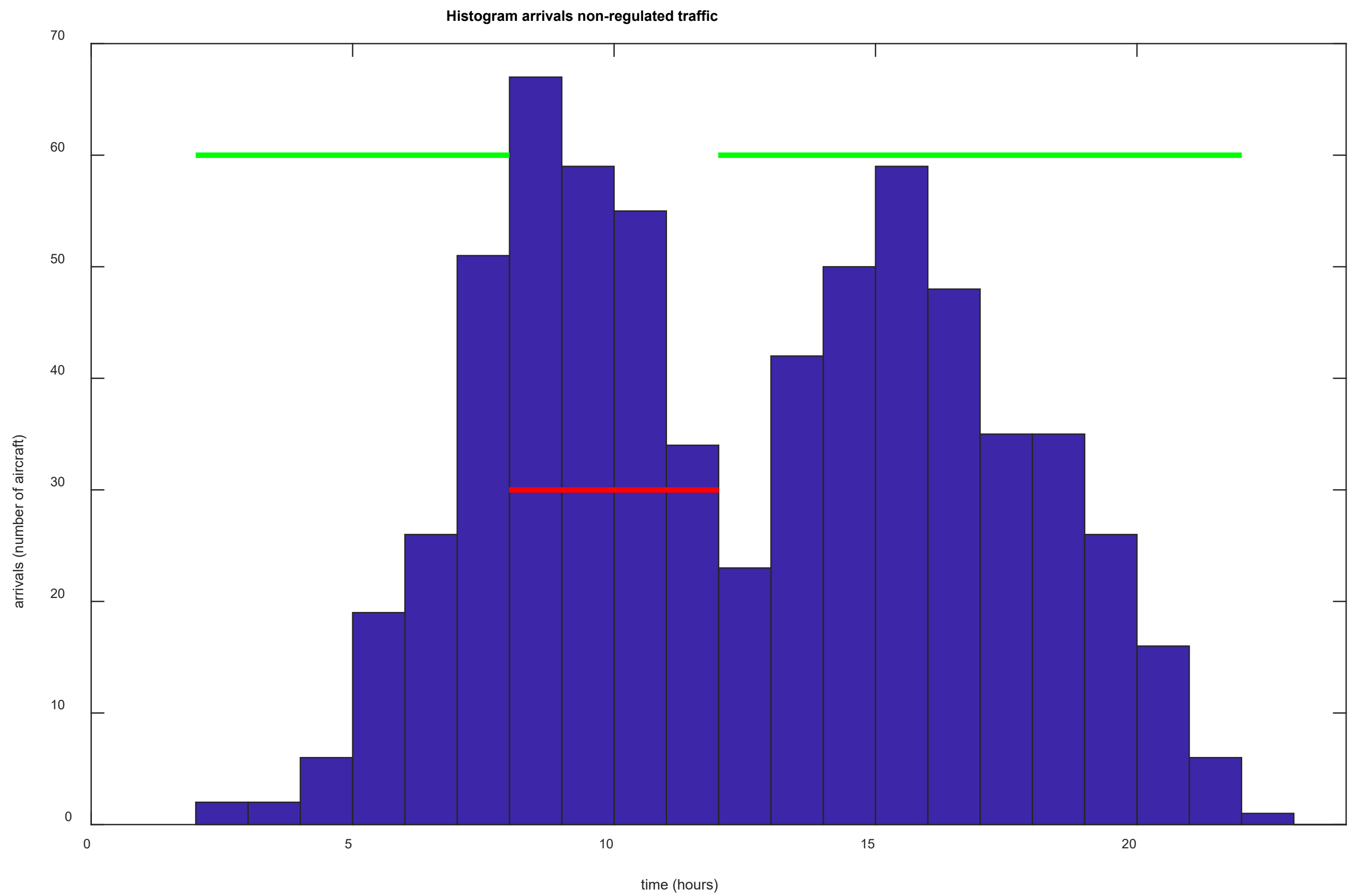
   Please consider at least **5 hours of reduced capacity** (between `Hstart` and `Hend`)

These parameters have to be very clearly indicated in your final report

7. After that, calculate **end time of regulation** (`HnoReg`), see next slides

WP1: Traffic demand data

Example of 24h simulated arrival demand at Logan International Airport (BOS)



Nominal capacity has been plotted as a green line and reduced capacity as a red line.

WP.1: Regulation definition

Program a function that computes the aggregate demand and capacities, the minimum delay needed, and the hour when the regulation is no longer needed.

```
[HNoReg,delay]=aggregateDemand(STA,Hstart,Hend,PAAR,AAR)
```

This function will compute the aggregate demand as a function of time and generate a plot with this data.

WP.1: Regulation definition

Program a function that computes the aggregate demand and capacities, the minimum total delay needed and the hour when the regulation is no longer needed.

Example of the use of the function in your main file:

```
clear all; close all

% here you would need to load or import your data

...

% and then
[HNoReg,delay]=agregateDemand(STA,Hstart,Hend,PAAR,AAR)

>> HnoReg=[17; 50];

>> delay=4262;
```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WP.1: Regulation definition

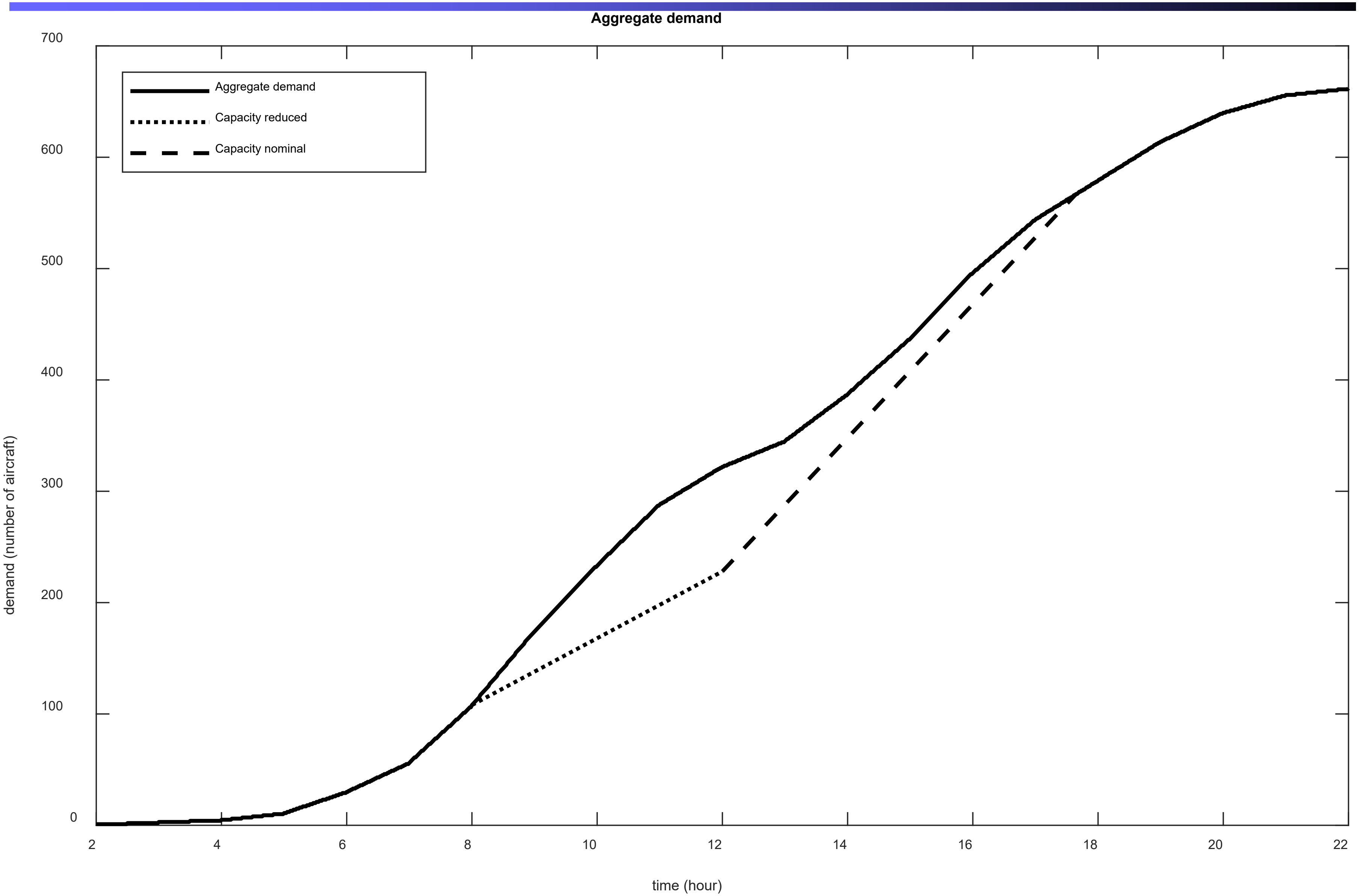
Use a matrix "`AggregateDemand`" to compute the aggregate demand. The elements in `AggregateDemand(:,1)` will be the time in minutes and the elements in `AggregateDemand(:,2)` will be the number of aircraft (check cumulative sum function in Matlab: `cumsum`).

Example:
```
STA = [… …;          AggregateDemand= [… …;
       …;                              490 120;
       491;                            491 121;
       493;                            492 121;
       493;                            493 123;
       …]                              … …]
```

means that at time 490 (8:10 am) the aggregate demand is of 120 arrivals. Do an entry in the matrix for each minute between the first and the last STA of the arrival demand within the regulated period.

Use same idea to compute the aggregate capacity of regulated period.

WP.1: Regulation definition



WP.1: Regulation definition

Note that the minimum total delay to realize is the difference between the demand and the capacity: the distance between the continuous and discontinuous lines.

This delay only depends on the regulation (not on how you solve the regulation). Check whether the average delay is large enough (>45min) so that the simulated regulation is interesting enough to study

Note that the results and the plot are only examples, with your data the plots will be different.

Avoid working with “hours”, convert the hours and minutes into minutes, and work only with minutes. Once you have the final result, transform it into hours and minutes to return the result and to do the plot.

WP.1: Regulation definition

Program a function computing the slots of the regulation:

```
slots = computeSlots(Hstart,Hend,HNoReg,PAAR,AAR)
```

function computes the matrix of slots from `Hstart` to `HNoReg`

Each slot line information should include: initial time of the slot, ID[1] of the assigned flight to that slot, and airline to which the slot has been assigned, both initially set to zero.

Size of the slots will vary according to the reduced (PAAR) and nominal capacity (AAR) of the airport.

[1] ID of flight can just be taken as its original position in the STA list of flights

WP.1: Regulation definition

Example of slots:

```
slots =[ ...    ... ...
         648    0  0
         650    0  0
         652    0  0
         654    0  0
         656    0  0
         658    0  0
         660    0  0
         661    0  0
         662    0  0
         663    0  0
         664    0  0
         665    0  0
         666    0  0
         ...    ... ...]
```

Note: Consider that when assigning the slots some of them might not be used (though not common during a regulation)

Therefore, you might consider adding some extra slots after `HNoReg` for some flights that might need them.

Once again you can use total minutes for slots also instead of hour minutes.

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WP1: Performance assessment: Introduction

SESAR looking to establish performance-driven network management culture (evolution of current process, mainly focused on delay reduction)

Requires agreed set of performance indicators to be used for real time performance monitoring, trade-off analysis, and what-if impact assessments

Indicators need to be dynamically selected according to network geographic interest scales and specific time horizons

Identify common local, regional, and sub-regional network performance indicators and their relationship to a selected set of network congestion mitigation strategies

[SESAR Solution, 2019]

PERFORMANCE AMBITIONS FOR 2035 FOR CONTROLLED AIRSPACE

www.atmmasterplan.eu/exec/overview/performance-ambitions

Key performance area	SES high-level goals 2005	Key performance indicator	Performance ambition vs. baseline			
			Baseline value (2012)	Ambition value (2035)	Absolute improvement	Relative improvement
Capacity	Enable 3-fold increase in ATM capacity	**Departure delay**[4], min/dep	9.5 min	6.5-8.5 min	1-3 min	10-30%
		IFR movements at most congested airports[5], million	4 million	4.2-4.4 million	0.2-0.4 million	5-10%
		Network throughput IFR flights[5], million	9.7 million	~15.7 million	~6.0 million	~60%
		Network throughput IFR flight hours[5], million	15.2 million	~26.7 million	~11.5 million	~75%
Cost efficiency	Reduced ATM services unit costs by 50% or more	**Gate-to-gate direct ANS cost per flight**[1], EUR(2012)	EUR 960	EUR 580-670	EUR 290-380	30-40%
Operational efficiency		**Gate-to-gate fuel burn per flight**, kg/flight	5280 kg	4780-5030 kg	250-500 kg	5-10%
		Additional gate-to-gate flight time per flight[2], min/ flight Within the: Gate-to-gate flight time per flight[3], min/flight	8.2 min (111 min)	3.7-4.1 min (116 min)	4.1-4.5 min	50-55%
Environment	Enable 10% reduction in the effects flights have on the environment	**Gate-to-gate CO_2 emissions**, tonnes/flight	16.6 tonnes	15-15.8 tonnes	0.8-1.6 tonnes	5-10%
Safety	Improve safety by factor 10	**Accidents with direct ATM contribution**[6], #/year Includes in-flight accidents as well as accidents during surface movement (during taxi and on the runway)	0.7 (long-term average)	no ATM related accidents	0.7	100%
Security	-	**ATM related security incidents resulting in traffic disruptions**	unknown	no significant disruption due to cyber-security vulnerabilities	unknown	-

1 Unit rate savings will be larger because the average number of Service Units per flight continues to increase.
2 "Additional" means the average flight time extension caused by ATM inefficiencies.
3 Average flight time increases because the number of long-distance flights is forecast to grow faster than the number of short-distance flights.
4 All primary and secondary (reactionary) delay, including ATM and non-ATM causes.
5 Includes all non-segregated unmanned traffic flying IFR, but not the drone traffic flying in airspace below 500 feet or the new entrants flying above FL 600
6 In accordance with the PRR definition: where at least one ATM event or item was judged to be DIRECTLY in the causal chain of events leading to the accident. Without that ATM event, it is considered that the accident would not have happened.

WP1: Performance assessment: Terminology

Key Performance Area (KPA)

A way of categorising performance subjects related to high level ambitions and expectations

Key Performance Indicator (KPI)

Current/past and expected future performance, & actual progress in achieving performance objectives quantitatively expressed by means of indicators

Indicators need to correctly express intention of associated performance objective: since they support objectives, they should not be defined without having a specific performance objective in mind

Indicators are not often directly measured. They are calculated from supporting metrics according to clearly defined formulas

[PJ19.04]

WP1: Performance assessment: SESAR KPAs

Selection of KPAs uses as reference set of KPAs defined in ICAO framework with refinements to support SESAR requirements

1. Safety
2. Security (e.g.: EUROCONTROL Data Snapshot Ransomware groups target aviation’s supply chain)
3. Environment
4. Capacity
5. Operational Efficiency
6. Predictability
7. Cost effectiveness
8. Flexibility
9. Access and Equity

[PJ19.04]

WP1: identify KPAs/KPIs (during all project)

The results of this project will have to be presented as KPIs (that belong to a specified KPA).

During each WP, you need to identify what KPIs can be computed (and classify them under KPAs).

For instance, in WP1, you are asked to compute the total delay of the regulation [min] or [h], that would be a KPI, and that can be considered under the “Capacity” KPA.

WP.2: Apply Ground Delay Program

Project planning

Weeks:	1	2	3	4	5	6	7	8	9	10
WP1 (Traffic+Reg)										
WP2 (GDP)										
1p progress report										
WP3 (GHP)										
WP4 (InterModal)										
WP5										
Oral test Deliver paper										

WP.2: Apply Ground Delay Program

Apply a Ground Delay program (see theory class) for this regulation affecting arrival flights between `Hstart` and `HnoReg` (controlled flights)

Compute the corresponding delay for each flight and other interesting KPIs (total air/ground delay, mean air/ground delay per flight, relative air/ground delay standard deviation, max air/ground delay, CO_2 emissions due to delay, on-time performance, etc.).

WP.2: GDP: determine flight status

Program a function computing the list of not affected, excluded and controlled flights

```
[NotAffected ExemptRadius ExemptInternational ExemptFlying
Exempt Controlled] = computeAircraftStatus
(STA,STD,Distances,International,Hfile,Hstart,HNoReg,radius)
```

From the arrival demand at the airport, this function computes which flights:

- are not affected by the GDP because their STA is earlier than the initial time of the GDP (`Hstart`) or because their STA is after the hour when the regulation is not active (`HNoReg`),

WP.2: GDP: determine flight status

Program a function computing the list of not affected, excluded and controlled flights

From the arrival demand at the airport, this function computes which flights:

- are exempt because their origin airport is further than the radius of the GDP
- are exempt because are already flying when the GDP is defined. That is, their STD is earlier than the file time of the regulation (Hfile). Consider a margin (30 min for example) to exempt the flights ready to depart at Hfile (already boarded, door closed, etc.)
- are exempt because they come from international airports
- are controlled (included in the GDP)

Each set of flights is a vector containing the ID of each flight.

WP.2: GDP: Assign slots and compute delays

Program a function assigning each flight to a slot and computing and the delay assigned and its kind (air or ground)

```
[slots,GroundDelay,AirDelay]=assignSlotsGDP(slots,
Controlled, Exempt, STA, STD, Hfile)
```

This function will assign slots to the flights that are arriving to the airport, assigning slots first to exempt flights, then to controlled ones (always respecting that a flight cannot arrive before its original STA).

AirDelay is considered as the delay to apply to all exempt flights

GroundDelay is considered as the delay to apply to all controlled flights

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WP.2: GDP: Assign slots and compute delays

Program a function assigning each flight to a slot and computing and the delay assigned and its kind (air or ground)

```
GroundDelay = [ …   …
                97    9
                101   14
                104   30
                106   32
                …     …]
```

Both delay matrices relate the ID of the flight with the amount of delay that has been assigned to that flight. From the previous example, flight number 97 has been assigned 9 minutes of ground delay.

WP.2: GDP: Assign slots and compute delays

Program a function assigning each flight to a slot and computing and the delay assigned and its kind (air or ground)

The matrix of slots will be completed by adding the ID of the flight assigned to each of the slots. See that, depending on the demand, some slots might remain unused (not very likely when demand is high, but not impossible), like in the following example (slot at 640, i.e. from 10h40 to 10h42):

```
slots = […      …   …
         630     95  A1
         632     96  A2
         634     97  A1
         636     98  A3
         638     99  A1
          640     0   0
         …        …   …]
```

WP.2: GDP: Assign slots and compute CTA

Program a function computing the CTA of the flights

```
CTA = computeCTA(STA, GroundDelay, AirDelay)
```

Compute the CTA of all flights from the original STA list of traffic and the delay assigned. CTA is the same as STA but with the delay added to the flights that have to do delay.

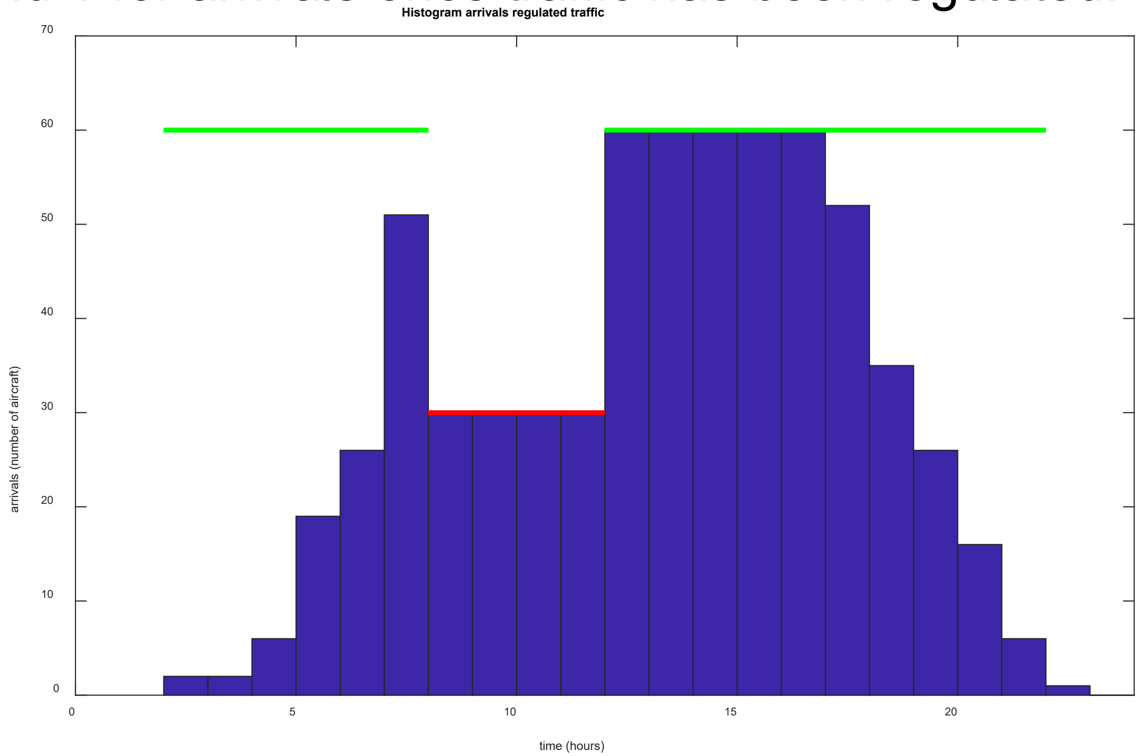
Alternatively, CTA can be obtained in your function `assignSlotsGDP`

At this stage, ATCSCC would send the controlled slots of arrival (and departure) to the airline.

WP.2: GDP: controlled histogram

Results: plot histograms `plotHistograms(STA,CTA,AAR,PAAR)`

Generate two histograms, one for arrival traffic before regulation (see slide 18) and 1 for arrivals once traffic has been regulated:



This serves to help checking if your GDP is correctly implemented

WP.2: GDP: unrecoverable delay

Compute the GDP unrecoverable delay

```
UnrecDelay =
ComputeUnrecoverableDelay(CTD,STD,Hfile,Hstart,GroundDelay);
```

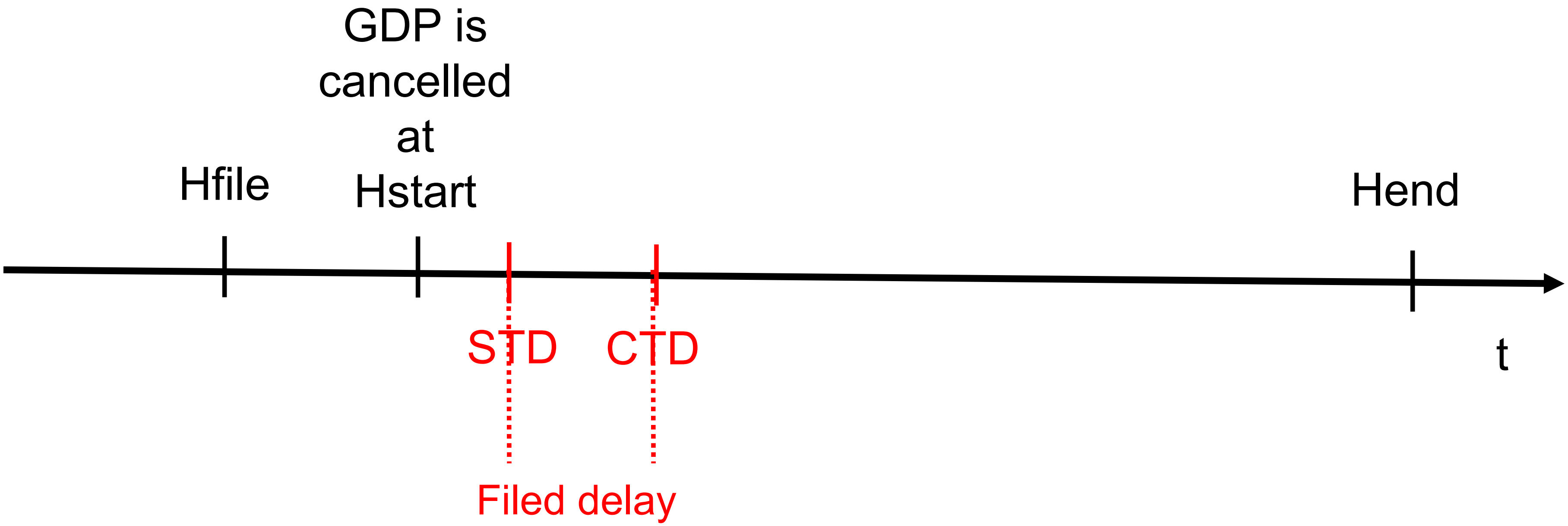
Make the assumption that the GDP is cancelled at `Hstart`, and thus no reduced capacity is needed anymore (nominal capacity).

You do not need to assign slots again, but from the GroundDelay previously computed, calculate the unrecoverable delay: delay that has already been done, even though the GDP is cancelled at `Hstart`.

WP.2: GDP: unrecoverable delay

Compute the GDP unrecoverable delay

Case 1: STD > Hstart → no unrecoverable delay, delay completely cancelled

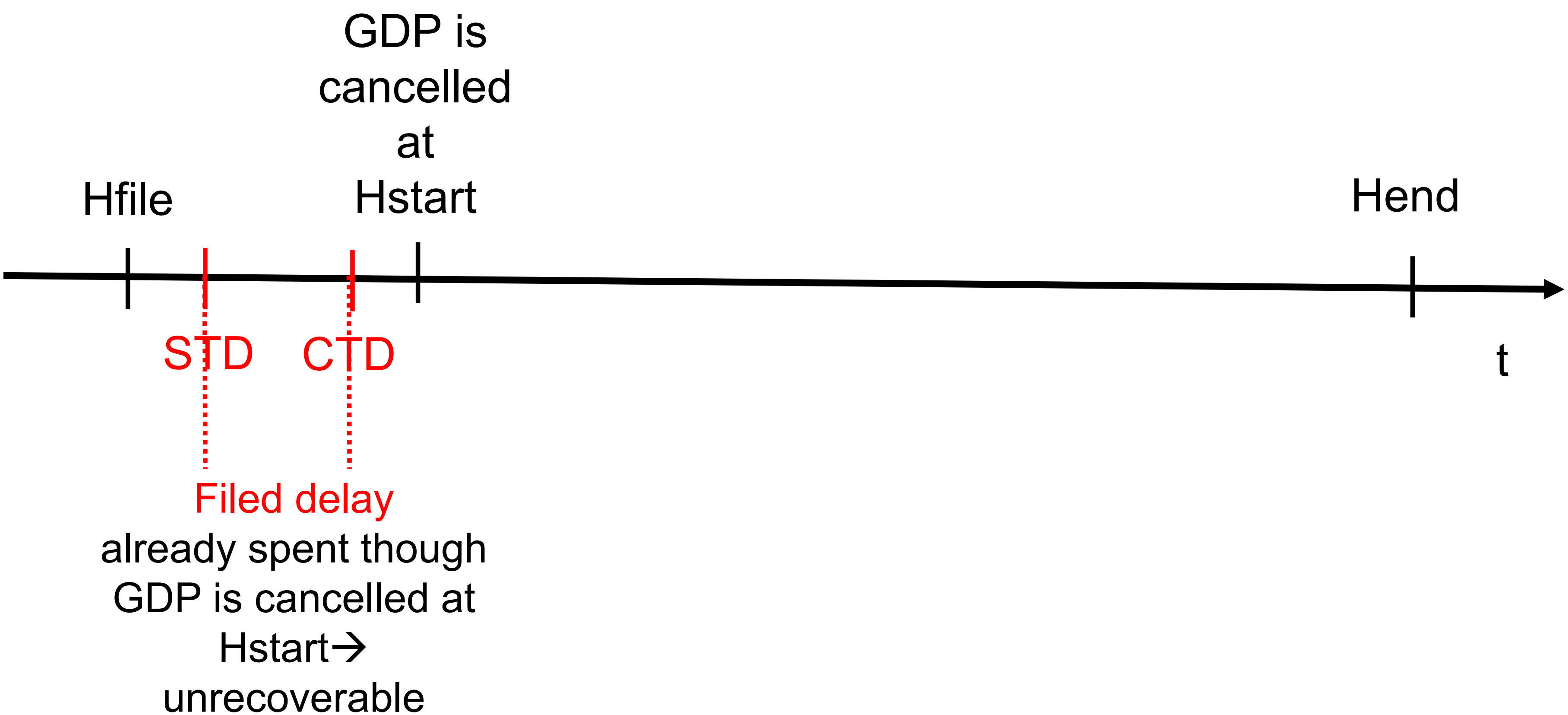


it was supposed to occur after GDP is cancelled → this delay is cancelled, i.e. it can be recovered

WP.2: GDP: unrecoverable delay

Compute the GDP unrecoverable delay

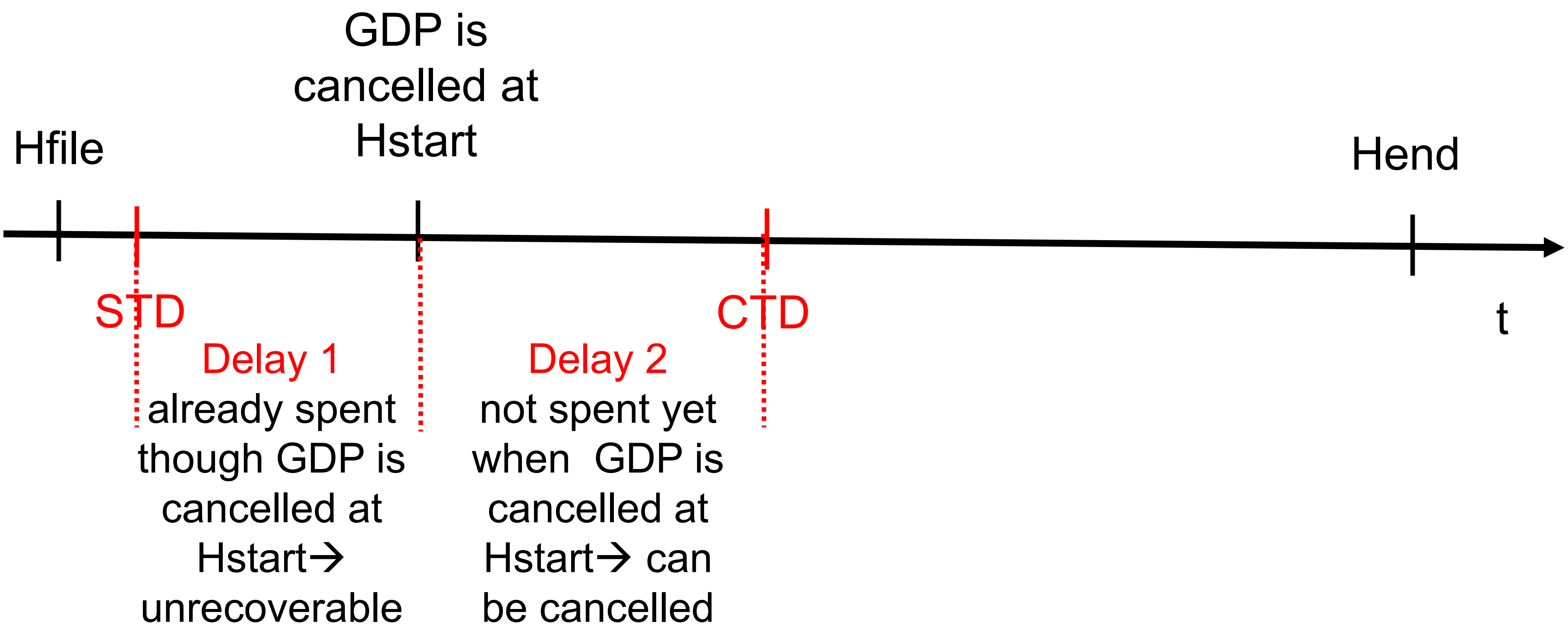
Case 2: CTD < Hstart → all assigned delay is unrecoverable delay, since it was already done when GDP is cancelled, unrecoverable delay = CTD-STD



WP.2: GDP: unrecoverable delay

Compute the GDP unrecoverable delay

Case 3: STD < Hstart & CTD>Hstart → 1st part of assigned delay is unrecoverable, since it was already done when GDP is cancelled, 2nd part can be recovered, supposing flight gets to leave at Hstart (ideal hypothesis)



WP.2: GDP effect of parameters

Compute CO_2 emissions due to delay

Look for references to translate minutes of delay (ground and air) into fuel consumption

Use one value of fuel consumption for each aircraft category (A to F)

Once you have the ground and air delay fuel consumption, calculate the total CO_2 emissions **due to delay** during the regulation, recalling (from Q and SEA) that 1kg of aviation fuel burnt generates 3.16kg of CO_2 [IATA Carbon Offset Program]

WP.2: GDP effect of parameters

Study the effects of changing the GDP parameters

Fix the parameters of the GDP, and by changing the *radius of exemption* and then the *file time*, study the effect of these parameters on several KPIs

Generate plots showing the trade-off between ground and air delay in minutes, CO_2 emissions due to ground and air delay, and unrecoverable delay (and any other KPI that you think can be of interest) as functions of the file time and the radius of exemption.

From these plots define an optimal value for the radius of exemption and the file time

WP.2: GDP: cancellation/substitution

Using R and Hfile previously chosen, simulate now that one airline (one with lots of flights at your airport) decides to cancel all flights with high delays (for instance > 2 or 3h depending on your airport)

Perform the second slot-assignation of GDP (after cancellations)

1. Identified flights to cancel and eliminate them from the controlled slots

2. Apply substitution for the chosen airline (maintaining original order of flights)

3. Once this airline has used all its emptied slots, apply compression in order to fill all slots.

Give the result of the new assignment of the aircraft to the slots and the delay assigned to each flight, for instance in a graphical way

Identify interesting KPIs for this part (number of cancelled flights, decrease of delay in remaining flights for this airline, etc.)

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WP.2: GDP: Evaluate KPIs

Importance of performance measure of the GDP in your report:

Identify KPAs and compute and analyze at least the following KPIs:

- total, maximum and average delay that are realized as ground delay
- relative standard deviation of ground delay
- CO_2 emissions due to ground delay
- same KPIs for air delay
- other KPIs such as: number of flights delayed, number of flights delayed with more than 15 min (OTP), etc.

Again, any other plots/results that you find interesting should be added to your report and will be valorized

WP.2: A remark about total delay

We recall that the total delay is constant for any method applied and depends only on the hypothesis of the regulation

Nevertheless some groups may experience very small variations of total delay (a few minutes). This is due to the change of order of the flights when your slots are of several minutes as illustrated in the following example, where F2 is an exempt flight when applying GDP:

Flight	STA	Slots	RBS		GDP	
			Assignment	Delay	Assignment	Delay
F1	8.00	8.00	F1	0	F2	0
F2*	8.01	8.02	F2	1	F1	2
F3	8.02	8.04	F3	2	F3	2
F4	8.03	8.06	F4	3	F4	3
Total delay:				6		7

Since the variation of delay is small (usually <<1%) with respect to the total of delay, you can neglect this difference in your conclusions

MGTA references

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