Adopt an Airport Project: Frankfurt (EDDF)

Final Report (May 2024)

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Abstract — This document presents a study on various air traffic management (ATM) strategies at an airport using different methods such as GDP, GHP, and an intermodal approach for passenger transportation.

The main objective of this project is to examine the impact of implementing various ATM methods, analyze and compare them, as well as evaluate their repercussions on performance indicators (KPIs) based on different areas (KPAs).

Furthermore, it aims to identify the consequences for airlines, the airport, air traffic controllers (ATC), airspace, and the environment, among others. The study focuses on the main airport of Frankfurt, EDDF, specifically on January 29, 2016, although this information is redundant as the study can be applied to any other day with the same amount of initial data.

We have tried to capture our knowledge in the most rigorous, accurate and obvious way possible. We hope it will be of your liking. For any questions or clarifications, we are at your disposal through our emails. MATLAB will be used as a support tool.

Keywords — DLH: Lufthansa, GDP, GHP, Intermodality, KPA, KPi

I. Introduction

Occasionally, phenomena can occur that directly or indirectly affect the field of aviation, which implies the need to apply different regulations to deal with these eventualities. The operational capacity of an airport is of great importance and can be influenced by various causes, the most common of which is adverse weather conditions. In this context, different measures are proposed to manage a period of regulation, such as the Ground Delay Program (GDP), the Ground Holding Problem (GHP) and an intermodal method to manage the demand of an airport, which are subject of study in this project. These strategies will be applied and analyzed at Frankfurt Airport (EDDF) and subjected to a comparative process in order to determine which generates the least costs and minimizes delays as much as possible.

II. Flight Data Compilation

To gather data for the study, the "20160129.ALL_FT+" file located in the compressed folder "20160129Data" on ATENEA [1] was used. Additionally, an Excel file for the same day and period was downloaded from NEST. This eased the combination of information from both files to acquire various data about the same flights.

This process ensures the maximum amount of data for all flights. Later, all the data was stored in a .mat file to accelerate the loading process whenever there is a need to work with it. Hence, a file containing comprehensive and accurate information about all flights worldwide for a specific day and period has been created. After completing this process, flights with Frankfurt Airport destination were filtered using the ICAO code EDDF. Additionally, scheduled departure and arrival times were converted from UTC to the local time of the study airport (GMT+2).

Thus, the data obtained for any flight includes origin, scheduled departure, scheduled arrival, flight delay, call sign, airline code, flight length (NM), destination, aircraft type, flight ID, and wvc.

A number of passengers were assigned to each flight based on the aircraft model.

III. Regulation Definition and Parameters Selection

With the aim of defining our regulation, a set of parameters must be defined, having been previously studied to observe how they affect our regulation.

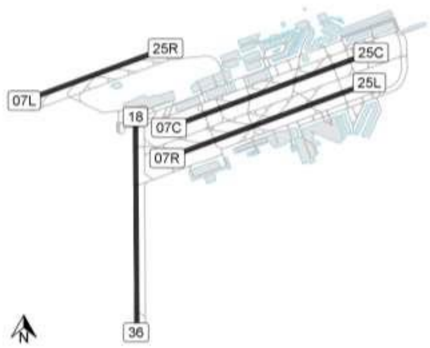

Figure 1. Frankfurt Airport Chart [2]

In view of the minimum operating conditions at Frankfurt Airport and after reviewing an AIRPORT CAPACITY IMBALANCE [2] study conducted by EUROCONTROL for several airports, it has been determined that Frankfurt Airport will operate with the configuration ARR:07L – DEP:07R (see Figure 1). With this configuration an Airport Arrival Rate (AAR) has been selected, a nominal capacity of 60 flights per hour.

For determining the Programmed Airport Arrival Rate (PAAR), that is the reduced arrival capacity of the airport, very bad weather conditions are assumed to happen for a certain period. So, a PAAR of 20 flights per hour has been selected, notably reducing the capacity.

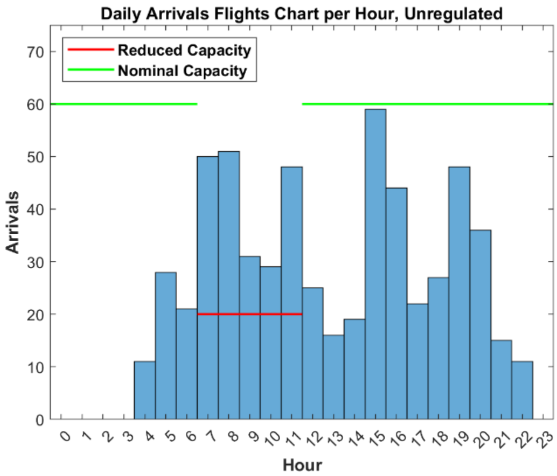

Figure 2. Arrival Flights per Hour

Figure 2 represents the flights that arrive at Frankfurt airport per hour, with the parameters AAR and PAAR commented before depicted on the figure.

The hour of the start of the reduced capacity is named Hstart and is 7:00 am, and the hour of the end of the reduced capacity is Hend, and is 12:00 am. The time when the regulation is set and the regulated slots are sent to the airline is Hfile, and is 4:00 am. Also, a radius of exemption of 600 nautical miles is selected, this radius means that if any flight departs from an airport outside the radius of exemption it will not be affected by the regulation.

The values of Hfile and radius have been firstly selected and afterwards validated studying what happens to air, ground and unrecoverable delay when changing the values of these parameters, but this validation will be explained in section IV.

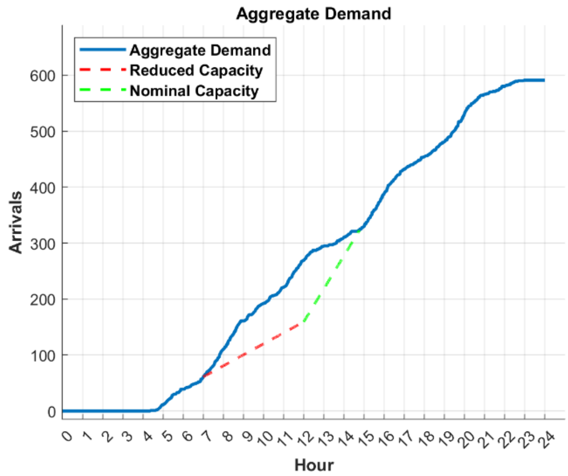

Figure 3. Aggregate Demand

It is important to note that the airport's return to full capacity does not correspond with the end of the regulation. To determine the end time of the regulation, the graph in Figure 3 has been computed.

This graph shows the hourly arrivals at the airport, with the red line representing arrivals at reduced capacity, the green line indicating delayed arrivals arriving at full capacity, and the intersection between the green line and the blue line represents the end time of regulation, known as HnoReg, which equals 14:46:24 and is when the airport has returned to normal operation.

Also, the area between the red, green, and blue lines represents the total delay, that is constant regardless of the type of regulation.

IV. Ground Delay Program

The GDP (Ground Delay Program) is a method to manage a regulation, which is applied to reduce the delay time to some privileged aircraft during the established regulation. This strategy does not take into account the cost of arriving at a certain slot with a certain aircraft, it considers the origin, the length, the Estimated time of departure (ETD) and the Estimated time of arrival (ETA).

For this purpose, different exemptions will be applied following certain requirements that will be determined below. It should be emphasized that the Ground Delay Program is applied exclusively in the established regulation schedule.

Firstly, for an aircraft to be exempted, it must have departed before the time at which the regulation is scheduled, the Hfile plus a 30 min margin for the flights that are almost ready to depart. Also, an aircraft coming from outside the radius of exemption or coming from an airport outside the ECAC

(European Civil Aviation Conference) [3] area will also be exempted.
On the other hand, there are controlled flights, that are all the flights that are under the jurisdiction of the stakeholder manager and are not exempted by radius, nor by Hfile.

For GDP slot allocation, exempt flights are prioritized, followed by controlled flights. Air delay is the delay applicable to all exempt flights, and ground delay is applicable to all controlled flights. Flights experiencing air delays are prioritized due to their more significant impact, including rerouting to avoid congested areas and holding at the destination, resulting in increased fuel consumption. Therefore, ground delay is considered a better approach.

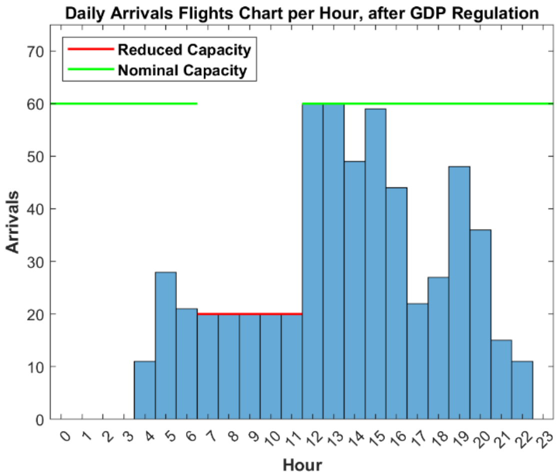

Figure 4. Arrival Flights per Hour after GDP

After all flights are allocated their slots, the number of arrivals each hour stays below the reduced capacity. This can be seen in figure 4.

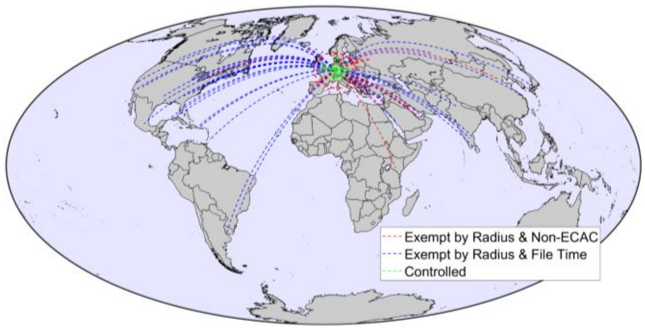

Figure 5. Frankfurt Arrivals Map at Regulation

In figure 5 we can see the different flights, ones exempt by radius, others exempt by Hfile, and others exempt for coming outside the ECAC, and the controlled.

A. Hfile and Radius validation

Having explained the delays that are present in the study, the validation of Hfile and Radius can now be done to determine if the chosen values where optimal.

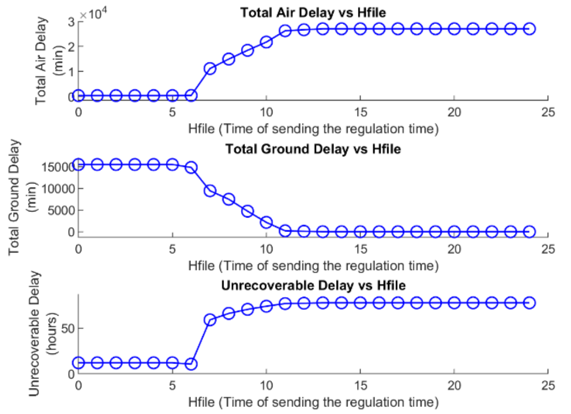

Figure 6. Trade-off Hfile

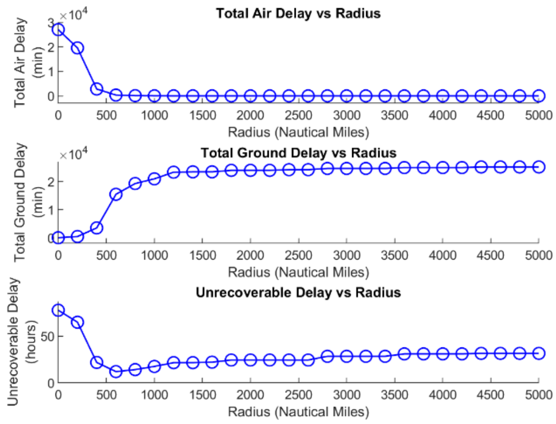

Figure 7. Trade-off Radius

Figures 6 and 7, are the graphs computed to validate the values of Hfile and Radius. The later the Hfile, the larger the air delay will be, as there are more exempt flights. The opposite happens for the ground delay as there will be more air delay. The unrecoverable delay also increases when the Hfile is later, until it cannot increase more and remains constant.

The inverse situation happens when having a bigger radius of exemption, as for example, if the radius is very large, there will be less exempted flights and therefore more ground delay. Here, the unrecoverable delay decreases when increasing the radius and again it remains constant at some value of the radius.

From the graphs, the values selected earlier appear to be the best choice. With the chosen Hfile and radius values, ground delay is at its maximum for that Hfile and almost reaches the maximum for that radius. Meanwhile, air delay and unrecoverable delay are minimized in both cases.

B. Cancellation Slots

Sometimes, when an airline operates several flights to a common destination, and there is a regulation, it may choose to cancel some flights due to accumulated delays. This measure frees up time for another aircraft of the same airline, which helps to reduce the total delay suffered by the airline. First, a check of Lufthansa-operated flights is carried out to identify those with a ground delay of more than 3 hours and 15 minutes. Once a flight that meets these characteristics has been identified, it is cancelled, thus freeing up the space allocated for that flight, followed by a further review of Lufthansa flights in order to reallocate them to the previously released space. If it is not possible to reassign these slots to flights of the same airline, the best available alternative is sought, even if it means allocating flights from other airlines, to optimize the use of the available slots. In reality, airlines sell these unused slots between them.

	Before Cancellation	After Cancellation
Number of DLH Flights	165	118
Total Air Delay (min)	169	169
Total Ground Delay (min)	20779	5149
Mean Air Delay (min/Flight)	4	4
Mean Ground Delay (min/Flight)	168	67
Total Ground Cost (k€)	405.20	84.77
Mean Ground Cost (€)	3268	1101
Delay Relative Standard Deviation	71.89 %	99.56 %

Table 1. Lufthansa Performance Improvement

It is logical to observe a significant decrease in the total delay and in the total ground delay generated once Lufthansa flights exceeding the 3 hours and 15 minutes threshold are cancelled. Prior to the cancellation, the airline accumulated a total of 20779 minutes of ground delay, while after the cancellation, this delay is significantly reduced to 5149 minutes, a 65.22% of ground delay and a 70.08 % of total ground cost have been reduced. This reduction is due to the cancellation of several flights that exceeded the established limit. In total, 47 flights were cancelled to mitigate the accumulated delay and improve the operational efficiency of the remaining flights.

V. Ground Holding Problem

"The GHP is a constrained multi-objective optimization (MOO) problem. Its objective is to ensure a smooth flow of aircraft through the airspace, avoiding congestion and delays, and in cases where delays are unavoidable, minimize their impact on airspace users" [1]. The same regulation period as GDP will be used.

To solve this problem, a series of constraints are used, which are as follows for the case of our study:

1. An aircraft cannot arrive at a certain slot before its scheduled arrival time.
2. At most, one flight can use a slot.
3. One flight must go to one slot.
4. Flights should not have more than a 30-minute air delay, so if the air delay exceeds 30 minutes, an additional penalty is applied.

The cost associated with a flight arriving at a specific slot is formulated as:

$$c_{i,j} = r_i \cdot delay_j^{1+\varepsilon}$$

Equation I. Cost Equation. [1]

Where 'I' refers to a flight and 'j' refers to a slot. Thus, the function to be minimized is:

$$\min\left[\sum_i \sum_j c_{i,j}\, x_{i,j}\right]$$

Equation II. Total Cost Function to Minimize. [1]

The variable r_i of Equation I is calculated based on the type of aircraft, the type of delay (AIR or GROUND).

To obtain realistic values of r_i for the several types of aircraft, the costs associated with different time periods and types of delay have been considered by the research group at the University of Westminster [4]. Using the information from Table 26 and Table 28 of the "European airline delay cost reference values," a system of 2 equations with two unknowns variables, r_i and ε_i has been proposed. Assuming that the costs they have determined can be represented by a function similar to Equation I to obtain an r_i and a ε_i for the diverse types of aircraft, the different ε_i obtained for each aircraft, and then with all ε_i calculated for each aircraft, a mean ε have been calculated to be used for calculus, that is $\varepsilon = 0.2463$.

For aircraft not included in Tables 26 and 28, a cost index r_i has been calculated for each of them. This calculation is based on the most used aircraft cost index present in the tables, specifically at Frankfurt Airport, the A320. This index is divided by the number of passengers on the A320, resulting in a $\frac{r_i}{A320\ \text{pax}}$, expressed in units of cost per minute per passenger, cost r_i for the other aircraft that are not in the tables, this index of the A320 is taken as a reference and multiplied by the number of passengers of the aircraft to be evaluated, thus obtaining the product $\frac{r_i}{\text{A320 pax}} \cdot aircraft\ pax$, this gives a cost index r_i for each aircraft.

It may stand out that figure 4 will be the same for GHP slots assignation.

To calculate $r_{airline}$ for non-equal slot allocation, it has been calculated by averaging the prices of all airlines such that where $r_{airline} = \frac{mean\ airlines\ prices}{mean\ airline\ price}$ in this way $r_{airline\ Low-Cost} > r_{airline\ Traditional}$ since the prices of low-cost airlines will be below the average making $r_{airline\ Low-Cost} > 1$, will perform the function of multiplier and for traditional airlines $r_{airline\ Traditional} < 1$ will perform the function of reducing the cost, which will make the optimizer tend to allocate those low-cost airlines before the traditional airlines to minimize the cost.

$$c_{i,j} = r_i \cdot r_{airline} \cdot delay^{1+\varepsilon}$$

Equation III. Non-Equity Slots Allocation Cost Equation

A. Low-Cost Airlines Slots Assignation Vs Traditional Airlines

In this section, the diversity of airlines operating different aircraft has been considered, as different airlines adopt various philosophies regarding the type of company they want to be. This translates into the costs generated by the delays of their flights and the costs their customers may generate. Therefore, low-cost airlines tend to minimize costs to the maximum extent, especially during peak periods, contrasting with traditional airlines or those with higher ticket prices. To adhere to this philosophy, efforts should be made to prioritize low-cost airline flights over traditional airline flights.

This entire process is not realistic because it would not comply with the KPA of equity, as all airlines would not be treated equally.

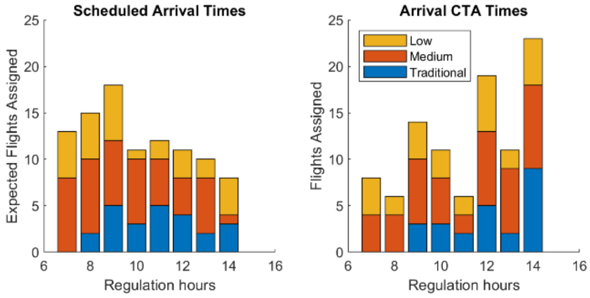

Figure 8. Non-Equity Slots Assignation, Low-Cost Airlines Vs Traditional Airlines in the Regulation.

For the last hour of the regulation have been assigned: 9 flights of traditional airlines (39.13 %), 9 flights of medium cost airlines (39.19 %) and 5 flights of low-cost airlines (21.74 %).

In these graphs, we have not considered the main operator of Frankfurt Airport, DLH, because otherwise the privilege of slot allocation for low-cost airlines compared to Traditional and/or medium-cost airlines would not be clearly visible.

B. Equity Slots Assignation

In this section, no distinction has been made between Low-cost Airlines, Medium-cost Airlines, and Traditional Airlines, ensuring that the optimizer pursues the best solution while maintaining equity criteria.

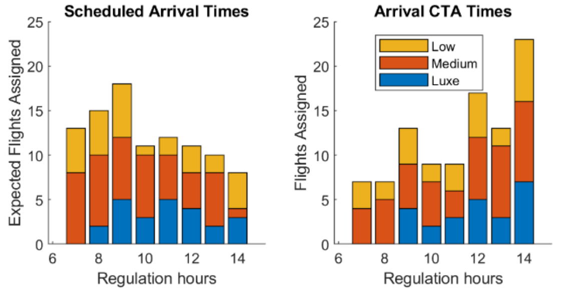

Figure 9. Equity Slots Assignation, Low-Cost Airlines Vs Traditional Airlines in the Regulation.

From figure 9, it can be observed that there is no clear distinction between airlines operating a certain aircraft, especially in the last hour of regulation. At the last hour of the regulation have been assigned: 7 flights of traditional airlines (30.43 %), 9 flights of medium cost airlines (39.13 %), 7 flights of low-cost airlines (30.43 %). From sections A and B and from figure 8 and 9, for the non-equal allocation of slots, it allocates 28.57% more flights operated by traditional airlines compared to the equal allocation, which allocates the same amount of flights operated both by traditional airlines and by low-cost airlines, from this result it can be concluded that the allocation of slots in an egalitarian way is totally equitable.

From previous sections must be taken into account that a penalty has been applied to all those planes that have an air delay greater than 30 min to arrive at a certain slot, “To bring this scenario closer to reality, which means that it is not easy to appreciate the privileging of low-cost airlines compared to traditional or medium-cost airlines.

VI. Intermodality

The primary objective of this section is to analyze the feasibility of substituting flights arriving at Frankfurt Airport with train travel during the period of regulation, aimed at enhancing sustainability and efficiency while reducing CO2 emissions and air traffic congestion around the airport vicinity. This study has been done with the help of EcoPassenger [5]. Furthermore, passenger transit times between the airport and downtown areas can be reduced, particularly for flights prone to significant delays.

Flights with train travel times of less than six hours will be substituted. Out of the 591 flights being analyzed, 58 have been substituted, with 42 of these occurring within the period of regulation, which will be the primary focus of the analysis.

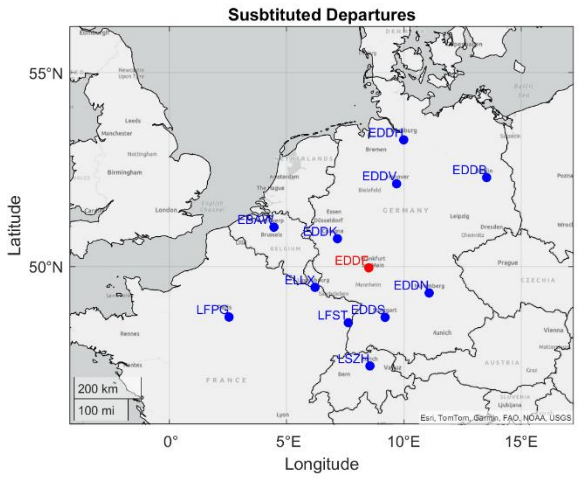

Figure 10. Substituted Departures Map

In Figure 10, the origins of all substituted flights are depicted, with Paris being the farthest origin observed.

Substituted Departures (from smallest to largest distance with respect to Frankfurt): EDDS (Stuttgart), **EDDN** (Nuremberg), **EDDK** (Cologne Bonn), **ELLX** (Luxembourg), **EDDV** (Hannover), **LSZH** (Zurich), **EBAW** (Antwerp International Airport), **EDDB** (Berlin Brandenburg), **EDDH** (Hamburg), **LFPG** (Paris Charles de Gaulle).

A. *After substitution data*

After the substitutions are made, the former data changes, resulting in a new scenario in which our results change notably.

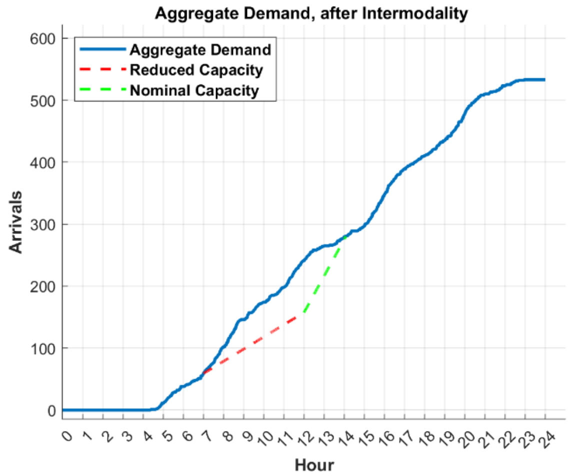

Figure 11. Intermodality Aggregate Demand

Compared to the aggregate demand of figure 3, the total delay has reduced as the area between the blue, green and red line is smaller, and the hour that the regulation finishes is different, with the one before the substitution being before the one with no substitutions. As flight demand has reduced, the workload of air traffic controllers has also been reduced. This is something that can affect certain Key Performance Indicators (KPIs), such as shorter runway wait times, improved airspace efficiency, and reduced congestion.

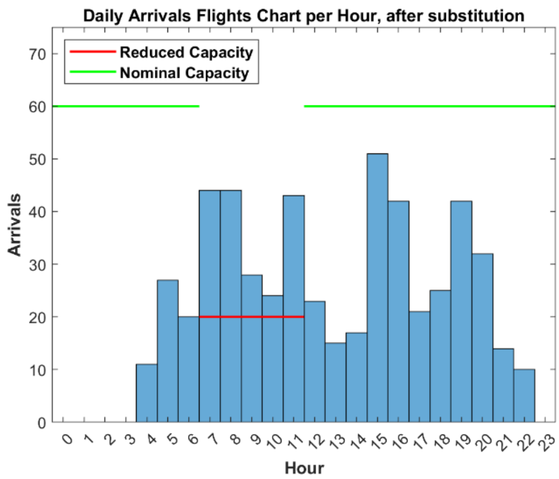

Figure 12. Arrival Flights per Hour after substitution

Although demand is lower, from Figure 12, it is clear that regulation is still necessary because the demand is much higher than capacity during the period of regulation.

	Mean Delay (min)	*Total Delay (min)*	*End of regulation*
Before substitution	104.8	27088	14:46:24
After substitution	87.3	19044	14:04:42

Table 2. Mean Delay and End of Regulation before and after substitution

In table 2 the data commented on before is resumed. The significant reduction of the total delay can lead to improved flight punctuality, enhanced passenger satisfaction, increased operational efficiency, reduced costs for airlines and airports, and overall smoother travel experiences.

B. CO2 emissions and door-to-door travel times comparison

For the substituted flights, the total amount of CO2 emitted has been calculated for both train and plane, resulting in a total of 5909 kg for planes and 586.2 kg for trains.
When we compare the door-to-door travel time of plane and train, we expect the flight time to be much shorter than the train time, as for the substitution to be feasible, the flights must be short.

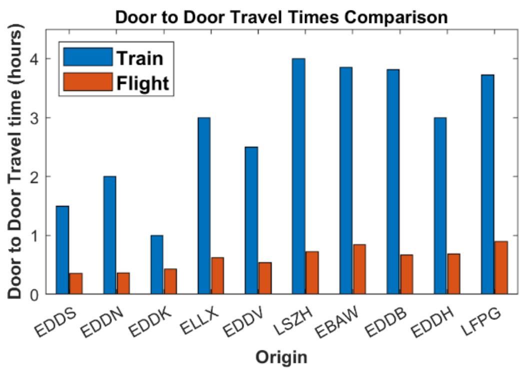

Figure 13. Door to Door travel times comparison

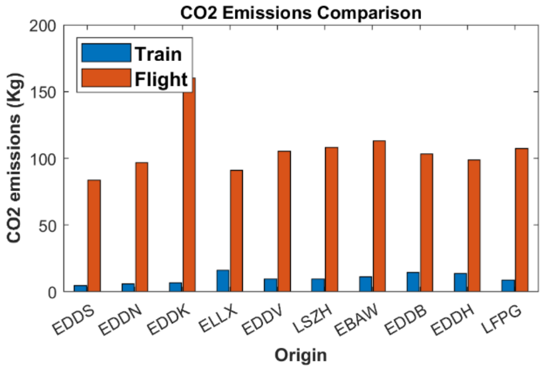

Figure 14. CO2 emissions comparison

In Figures 13 and 14, the door-to-door travel times and the CO2 emissions of train and plane have been compared for every origin that has been substituted, with the origins sorted from closer to farther from Frankfurt airport. From the figures, on the one hand it is obvious that the train is more beneficial than the plane from an environmental point of view but on the other hand travel times are significantly longer when travelling by train.

It is important to remember that the last comparison is made when GDP or GHP have not been applied, so the time a passenger takes in total travelling by plane can be much longer than with train if its flight has a high delay.

To determine if Intermodality is worth applying, environment and operational efficiency KPAs must be studied. These KPAs have been studied in this section.

C. GDP After Intermodality

After Intermodality, GDP is applied again to the new set of 533 flights, where 225 are in the regulation period, so new data is obtained.

	GDP Before substitution	*GDP After substitution*
Unrecoverable Delay (hours)	12.03	11.35
Air Delay (min)	359	356
Ground Delay(min)	26729	18688
Max Ground Delay (min)	257	250
Max Air Delay (min)	19	19

Table 3. GDP delays before and after substitution comparison

	GDP Before substitution	*GDP After substitution*
Air Delay Cost (k€)	35.53	35.33
Ground Delay Cost (k€)	450.39	316.34
Total cost (k€)	485.92	351.67

Table 4. GDP costs before and after substitution comparison

From Tables 3 and 4, it is seen that ground delay has been reduced to 8041 min, resulting in a reduction of 134.06 k€ of the cost of the ground delay. Air delay practically has not been affected. Also, the amount of delay that can be recovered has increased, the maximum ground delay has just reduced 7 minutes, and the maximum air delay is equal for both scenarios.

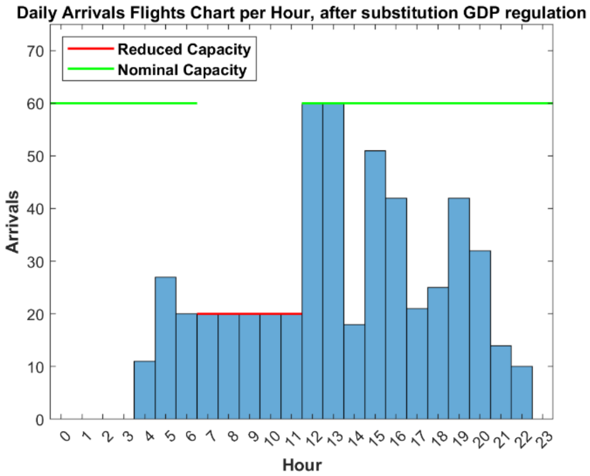

Figure 15. Arrival Flights per Hour GDP after substitution

Figure 15 shows the new histogram of arrival flights after applying GDP when the substitutions are made.

D. GHP After Intermodality

Here, the same process as in section C is done, but in this case GHP is applied instead of GDP after Intermodality.

	GHP Before substitution	*GHP After substitution*
Unrecoverable Delay (hours)	11.77	10.60
Air Delay (min)	362	354
Ground Delay(min)	26707	18678
Max Ground Delay (min)	404	368
Max Air Delay (min)	30	30

Table 5. GHP delay before and after substitution comparison

	GHP Before substitution	*GHP After substitution*
Air Delay Cost (k€)	22.00	19.68
Ground Delay Cost (k€)	444.41	287.58
Total cost (k€)	466.41	307.26

Table 6. GHP costs before and after substitution comparison

With GHP, from Tables 5 and 6, it is seen that now ground delay has been reduced to 8029 minutes, resulting in a reduction of 156.82 k€ of the cost of the ground delay. The total air delay, the cost of this delay and the maximum air delay has remained practically unchanged.

VII. Results Analysis & Comparison

A. KPA's analysis

The main key performance areas (KPAs) in this project are Capacity, Environment, Operational Efficiency and Cost Effectiveness. SESAR requirements will be used as a reference for the analysis of each. Each area will be examined individually to understand its contribution to the project and how it aligns with the standards set by SESAR.

B. Capacity

This KPA is responsible for quantifying the capacity of an airport or air sector to manage arrivals. It can be considered that the primary objective of this project is precisely to regulate this capacity, becoming the fundamental pillar of the analysis.

Returning to Table 5, it is observed how the GHP after the application of Intermodality, manages to significantly minimize both ground delay and air delay, with records of 18678 and 354 respectively. It is important to note that the difference in delay between GDP and GHP after Intermodality is minimal, unlike before substitution, where a significant reduction in delay is observed.

C. Environment

The environmental aspect is one of the main pillars of this analysis. When addressing the issue of pollution, airplanes stand out remarkably compared to other modes of transportation, such as trains or automobiles.
The concept of environment is closely linked to the amount of delay faced by regulation. Whether this backlog is due to air or ground traffic, the air pollution problem is likely to be exacerbated.

Regarding pollution, it is important to note that a post-implementation analysis of the GHP has been carried out in order to compare the levels before and after applying Intermodality. When analyzing the data collected in the previous section, it is observed that before the substitution, an emission of 5909 kg of CO_2 was obtained, while after the implementation, 586.2 kg is obtained. This represents a reduction of more than ten times compared to the levels prior to the implementation of Intermodality. This result is consistent, given that airplanes are one of the modes of transportation that generate the most gas emissions, in contrast to the train, whose emissions are relatively low.

D. Operational efficiency

The main aim of this KPA is to increase productivity while minimizing costs and time. Implementing measures such as flight cancellations or Intermodality reduces the number of flights, resulting in decreased total delays, fuel consumption, and costs, as previously studied. This optimization enhances operational efficiency by improving resource management, reducing environmental impact, and optimizing schedules, air traffic control, and route planning. Also, these enhancements help air traffic controllers by reducing their workloads.

E. Cost effectiveness

This is the last KPA to be analyzed and focuses on determining which type of regulation results in a lower total delay cost, considering the delay cost per minute. In essence, the GHP regulation will be considered the most cost efficient, as it is based on calculating the cost per aircraft and thus determining the total cost.

As an essential part of the GHP strategy, the primary objective is to minimize delay-related costs. However, by applying Intermodality, an even more significant reduction can be achieved. By analyzing Table X in detail and comparing the costs before the implementation of GHP with those after the implementation of Intermodality, a notable difference is evident. Before GHP, the total cost was of 485.92 k€, whereas after the incorporation of Intermodality, these costs were reduced to 307.26 k€, representing a decrease of 178.66 k€. This considerable reduction underlines the positive impact that both GHP and Intermodality have in optimizing the costs associated with delays.

F. GDP Vs GHP

	GDP Before Substitution	GHP Before Substitution
Flights with zero Delay	40	60
Ground Delay (min)	26729	26707
Air Delay (min)	359	362
Mean Ground Delay (min/Flight)	169	169
Mean Air Delay (min/Flight)	3	3
Delay Relative Standard Deviation	96.27 %	112.73 %
Flights with more than 15 min of Ground Delay	156	152
Flights with more than 15 min of Air Delay	5	8
Max Air Delay (min)	19	30
Max Ground Delay (min)	257	404

Table 7. GDP Vs GHP Delay

	GDP Before Substitution	GHP Before Substitution
Ground Delay Cost (k€)	496.88	444.41
Air Delay Cost (k€)	34.49	22.00
Total cost (k€)	531.37	466.41
Mean Ground Cost (€/Flight)	3145	2813
Mean Air Cost (€/Flight)	328	209
Number of Flights with a cost greater than 5000	20	28

Table 8. GDP Vs GHP Cost

From the results of Table 7 and 8, it can be observed how GHP minimizes costs, a 12.23 %, compared to GDP by finding a balance between air delay and ground delay, unlike GDP, which seeks to minimize air delay without considering the cost implications of the total delay caused by regulation.

The GHP causes a slight increase in air delays, allowing some controlled flights to be assigned earlier. This, at the same time, reduces the ground delay and, therefore, its specific associated cost is reduced by 10.56 %.

On the other hand, it can be observed how the average delays, both in the air and on the ground, remain constant in both cases, but their cost is reduced with the implementation of the GHP.

VIII. Conclusions

The purpose of this project is to study the different ways of managing air traffic, as well as to evaluate the impact that the implementation of an intermodal modality has on demand during a period of regulation.

According to the study conducted, it can be concluded that the GHP method is optimal for slot allocation control from a cost perspective. This method slightly reduces costs related to delay, reaching a minimum compared to GDP. However, it is important to note that total delays, both in GDP and GHP, remain constant. Nevertheless, in the case of GHP, these delays are distributed less equitably, as reflected in the standard relative deviation of delay for GDP of 96.27 % and for GHP of 112.73 %.

However, GDP is the best strategy in terms of security as it prioritizes ongoing flights, ensuring they spend the least amount of time in the air.

Regarding cancellations that an airline could make for its flights, it is highly recommended to consider them, as it improves operational performance, reduces costs associated with delays, and increases profits. However, it is important to consider the implications of canceling flights, such as customer compensation, possible search for alternative accommodations, and passenger redistribution through other flights or offering different alternatives. Likewise, it is necessary to consider the costs associated with these actions, which may be higher or lower than canceling a certain number of flights, depending on the different philosophies and business policies of the airlines, which could be subject to study for another project.

In light of a decrease in air sector capacity and/or airports, it would be opportune to consider substituting certain flights with land routes traveling by train. This could improve the operability of the air sector, reduce flight demand, minimize delays and associated costs, as well as avoid an increase in environmental impact by reducing CO2 emissions derived from passenger transport.

IX. References

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Contributions

WP1:
J.C.A: Histogram
M.C.R: Aggregate Demand, Data Obtain, Frankfurt Filtering, Histogram
A.E.H: Nothing
WP2:
J.C.A: Compute Aircraft Status, Unrecoverable Delay, Compute CTA
M.C.R: Assign Slots GDP, Cancellation Slots & Substitution.
A.E.H: Compute Aircraft Status
WP3:
J.C.A: Nothing
M.C.R: Assign Slots GHP, Compute Flight Delay Cost
A.E.H: Nothing
WP4:
J.C.A: Substitution and comparison
M.C.R: Nothing
A.E.H: Nothing
WP5: A.E.H