RUNWAY/TAXIWAY SYSTEM CAPACITY ANALYSIS AT THE LISBON AIRPORT (LPPT-LISBOA)

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ABSTRACT

Increasing its airside capacity is a challenging issue for the Lisbon Airport, facing the biggest traffic growth ever. Considering the airport, framed by the city of Lisbon, there is no opportunity for extending the total airport area. Hence, it is crucial to find short time solutions to increase the capacity until the promised new Lisbon airport is open. This paper focuses on analyzing the runway and taxiway systems of the Lisbon airport through computer simulation using *Simmod PLUS!*. It presents practical suggestions to improve the current capacity in order to meet the short-term future traffic demand of the airport.

Keywords: Airport, Runway, Capacity, Simulation, *Simmod PLUS!*.

1. INTRODUCTION

The Lisbon Humberto Delgado Airport is now in terms of yearly passenger numbers one of the 30 biggest airports in Europe, hitting new records in every single month of 2016, with a total of 22.4 million passengers, a 11.7% growth relatively to the previous year (ANA Aeroportos de Portugal, 2017). Facing the current growth of the Lisbon Humberto Delgado Airport, it is imperative to find practical solutions to increase the airport capacity in the short term in order to accommodate the predicted traffic demand for the upcoming years. However, the city of Lisbon now fully surrounds the airport, making it impossible to make big modifications to the current airport layout in order to improve its capacity. The airspace around Lisbon is also a constraint to the airport capacity and a focus of study, specially due to military operations that severely reduce the available arrival and departure routes of the Lisbon Airport (EUROCONTROL, 2016), (Rodrigues, 2014).

The airfield of the LPPT has two runways, 03/21 and 17/35. Runway 03/21 is the runway used in a vast majority of the time and is the only runway configuration for LPPT (NAV Portugal E.P.E, 2016). Runway 17/35 may be requested by pilots when 03/21 is unsuitable for a particular operation. The airfield is served by two terminals, terminal 1 being the one used for the majority of operations and terminal 2 being used for departures by certain low-cost commercial airlines. Besides the commercial terminals, that do most of the operations at the airport, there is a cargo terminal, a small terminal for private flights and a military base.

The goal of this study is to evaluate the current airport capacity of the LPPT and identify possible enhancements so that the predicted higher demands in the upcoming years can be accommodated. Specifically, focus will be given to the runway and taxiway system performance of the airport, having gate capacity as well in consideration. To perform the study, a large scale airport simulation tool, *Simmod PLUS!*, is used.

2. BACKGROUND

The capacity of an airport, although being a concept widely used, has no generally accepted definition. International Civil Aviation Organization (ICAO) defines it as the number of movements per unit of time than an airport is able to achieve under different meteorological conditions (ICAO, 2009). However, some other definitions take into consideration the achievable Level of Service (LOS) when defining capacity, normally in the form of accepted average delay, while others take into consideration the number of achievable hourly movements over a period longer than one hour. An airport has within it a number of interconnected systems, as the airspace, runways, taxiways, gates and terminals. The capacity of an airport is the capacity of its least effective system, therefore all systems of an airport should be taken into account when assessing its capacity.

In this work, focus is given to the runway and taxiway systems. Runway capacity directly represents the number of airplanes that are able to arrive and depart from an airport over a certain period of time. It is influenced by the number of runways and its geometric layout, the Runway Occupancy Time (ROT), the separation requirements between aircraft, the traffic mix using the runway, the different type of operations being performed (No. of arrivals vs No. of departures) and the weather conditions. Taxiways determine the ability and the necessary time for airplanes to move between the runways and the gates. Being an adjacent system to the runway, it is critical that taxiways are able to effectively feed departures and alleviate arrivals from the runway, diminishing the ROT as much as possible. Taxiway capacity is not often referred to as it is rarely a limiting factor for an airport capacity. However, bottlenecks on the taxiway system can occur and its capacity should not be disregarded.

Different approaches can be taken in order to calculate the capacity of an airport, each having a different level of complexity. Historical approaches look at data collected in the past and perform an analysis to determine the evolving performance of the airport. If a degradation in performance is seen and sufficient data has been collected, conclusions can be drawn regarding which factors contributed to the performance degradation, providing a basis to where to focus possible future

capacity enhancements. Analytical models and look up tables provide another method of measuring the capacity of an airport based on previously calculated capacities taking into account changes in the different factors that are influential. However, this models and tables normally look at the runway capacity alone, disregarding all the other systems an airport has within itself. Simulation models, on the other hand, can provide a full gate-to-gate analysis and take into account all the different factors that influence an airport capacity, providing the analyst a full overview of the entire airport system.

3. METHODOLOGY

In order to perform the analysis of the Lisbon Airport, *Simmod PLUS!* is used as the airport simulation tool to create a model of the airport. This is a fast time simulation tool that describes the evolution of an airport over time by a mathematical model, the state of which changes at discrete points in time, determined by the occurrence of an event that changes the variables of the model. In order to model an airport, *Simmod PLUS!* uses nodes and links. Nodes are the points in space in which an aircraft position is evaluated in the system, and links define the paths that aircraft are allowed to travel between nodes. As the purpose of the simulation is to produce realistic results, not any ideal or specific case scenario, *Simmod PLUS!* takes a certain amount of variables as user defined probability distributions. In order to obtain realistic results, considering the amount of detail given to the model and to its random variables, several iterations of the same data set should be done in order to obtain statistically significant tendencies.

As mentioned in Section 1, runway 03/21 is the only runway configuration used in the LPPT. As runway 17/35 is very rarely used and only on pilot request, it is not modeled as a runway, but instead treated as a normal taxiway. Since the operational procedures and aircraft movements are extremely different depending on which runway is in use, 03 or 21, two different models are created in order to simulate the two different runways in use.

The weather conditions in which this work is focused are, for the sake of simplicity, clear sky with total visibility. As wind regularly affects operations at the Lisbon Airport, its effect cannot be ignored. Tests are made for winds between 0° and 90° with 30° intervals and wind speeds between 0 and 30 knots, with 15 knots intervals (wind directions are given relative to the aircrafts movement).

Two different traffic samples are used to test the airport model. One represents the current demand of the LPPT, being from an average day of the current year, 2017. It is obtained from two sources, the Portuguese Air Navigation Service Provider (ANSP), NAV Portugal, and an online database. In order to simulate the predicted increase in demand at the Lisbon Airport, a second traffic sample representing a medium term future demand is tested. In order to obtain this sample, several flights are added to the 2017 traffic sample, with special focus on the morning traffic peak.

NAV Portugal also kindly provided a data sheet with 1078 departures and 1020 arrivals collected in 2010, with important information to the simulation such as Runway Occupancy Time for Arrivals (ROTA), Runway Occupancy Time for Departures (ROTD), Flight Crew Reaction to Line-up Clearance (FRLC) and Flight Crew Reaction to Takeoff Clearance (FRTT).

4. IMPLEMENTATION

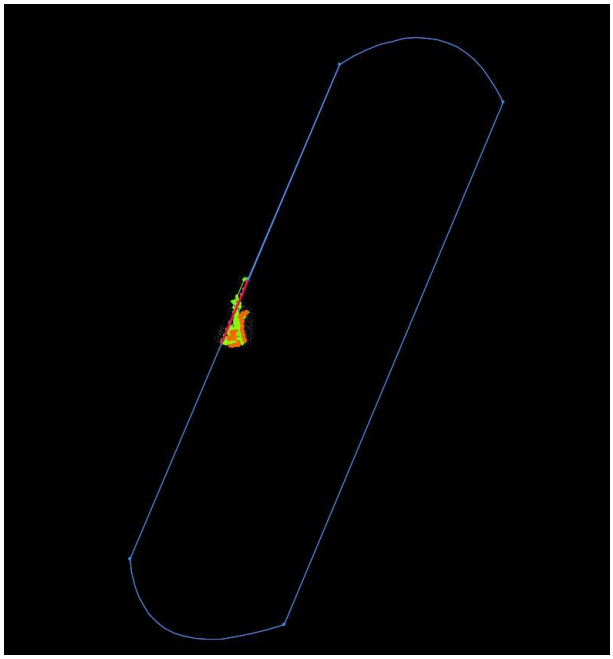


Figure 1: Model airspace.

The content present in this section is relative to the modeling of the current state of the LPPT, which serves as a base to obtain results and identify further possible enhancements to the airport. The changes done to the Lisbon Airport in the end of 2016 and beginning of 2017, published in the latest electronic Aeronautical Information Publication (eAIP) package, are included and modeled.

The model airspace can be seen in Figure 1Figure 1: Model airspace.. Only the initial or final seven nautical miles traveled by departing or arriving aircraft, respectively, are modeled. The nodes seven nautical miles away from the runway are the nodes where arrivals are injected in the simulation, and departures are ejected from the simulation. Altitudes are attributed to them accordingly. The blue route forming a circuit serves as a way of missed approaches retrying their landing, although it does not represent the real missed approach procedures for any of the runways. The main characteristics of the model airspace are minimum separation between aircraft, given for arrivals according to ICAO wake vortex categories and for departures according to aircraft performance after takeoff, and aircraft speeds, which in simulation are differentiated according to the same ICAO wake vortex categories, with a distinction between arrival and departure speeds. Note that in case an aircraft is departing between two arrivals, the minimum separation between arrivals increases to six nautical miles. In order to better simulate operational reality, all minimum separations are introduced as a random variable, defined in the interval [-0.25 0.25] nautical miles distance from the target separation.

Figure 2 shows the modeled airfield. The runway, shown in light red, is one of the most complicated modeled systems. For departures, all runway entry points and their usage probability according to aircraft category are simulated, as well as FRLC, Line-up Time (LUPT), FRTT and takeoff roll times. For arriving aircraft, all runway exits and ROTA, according to aircraft category, are simulated. When runway 21 is in use, the procedure of crossing the runway in order to reach its entry point that gives more Takeoff Distance Available (TODA) is also simulated.

The movement of aircraft through the taxiways between the runway and the gates is fully simulated, represented in green in Figure 2. Aircraft have different speeds according to the different conditions of the taxiway they are in (e.g., sharp turns have lower speeds than long straight taxiways).

The conflict between aircraft during their taxi process is also simulated and when needed, aircraft will hold to avoid collisions.

Gates are the nodes in the simulation at which aircraft will wait until it is time for them to depart. Some gates cannot be used at the same time, which is taken into account in the simulation. The types of aircraft that are able to use each gate is also considered, according to ICAO Aerodrome Reference Code, given according to wingspan. The pushback movement from a gate is also taken into account as well as the extra amount of time after pushback needed to remove the pushback tug and make final preparations for the flight.

All flights in the simulation go through the following process: injection at the arrival node, seven nautical miles away from the runway, land in the runway, take a runway exit and taxi to the assigned gate, wait for the departing time, taxi to the runway and takeoff, ejection from the simulation at the departure node, seven nautical miles away from the runway. The injection time and departing time are calculated from the scheduled Estimated Time of Arrival (ETA) and Estimated Time of Departure (ETD), respectively. To both times, a probability distribution is attributed in order to simulate the randomness of the exact time at which aircraft arrive or depart the airport. The attribution of a specific gate to each flight is not modeled, as the information needed to do so is not available. Instead, flights are attributed to a certain group of gates, called aprons, according to the type of flight and airline (e.g. commercial, cargo, low cost, etc.).



Figure 2: Model airfield

5. RESULTS

The results are obtained for a time interval of one day, according to the collected traffic samples being simulated. The data points are obtained as a 15 minutes moving hourly average, meaning that the analyzed variables are calculated for and averaged through a one hour time interval, with a 15 minutes increment. The data points have per basis the flights that happened within the defined time intervals, and not the time intervals themselves. The focus of the results is put on movements per hour throughout the day, average delay and breakdown of the origins of the delay. Note that in this work delay does not refer to the difference between ETD and Actual Time of Departure (ATD) or ETA and Actual Time of Arrival (ATA), but to the amount of time an aircraft has to be stopped, due to constraint reasons from different sources. The results here presented are only relative to the medium term future demand, as it is the one that requires a better performance from the airport model and from which conclusions are drawn.

5.1. Number of Iterations

The first step to make, taking into account the randomness and probability distributions introduced in the model, is to do a convergence study, in order to learn exactly how many iterations of the same data set are needed in order to obtain meaningful results. To do so, the analyzed variable is the runway maximum throughput. In order to obtain the maximum throughput, the simulation tool provides a cloning feature, where several flights can be cloned, creating an extremely high demand, that keeps the runway in constant use. The introduced random variable that directly influences the runway throughput is the separation increment. Note that given high enough demand, the runway is always being requested both by departures and arrivals, which makes it being used in a constant Arrival-Departure-Arrival sequence, at which point the separation increment to the minimum separation is the only variable that influences the runway maximum throughput and, given enough iterations, the maximum throughput value should be constant. By analyzing Figure 3, 10 iterations are chosen to perform the calculations.

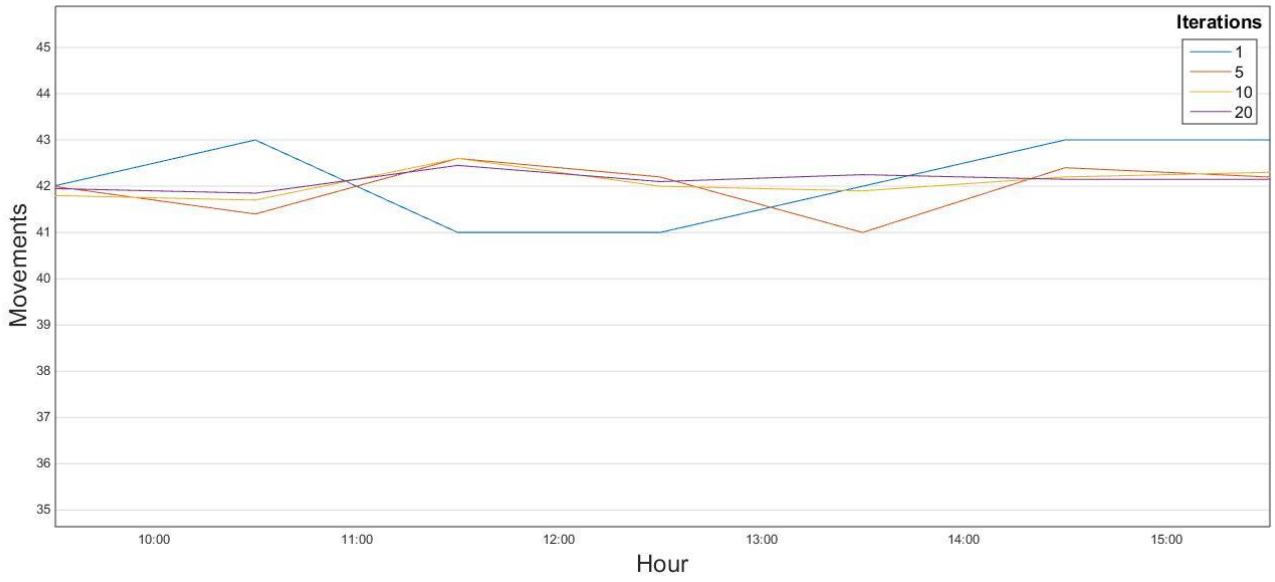
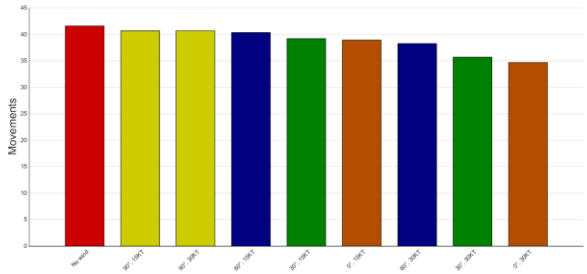


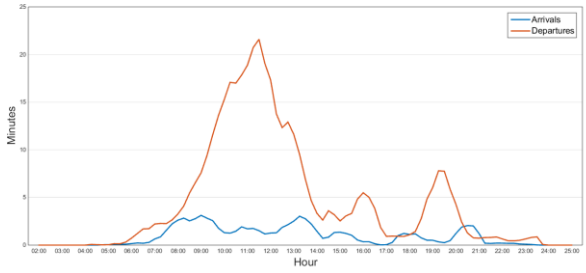
Figure 3: Maximum throughput convergence study.

5.2. Runway 03

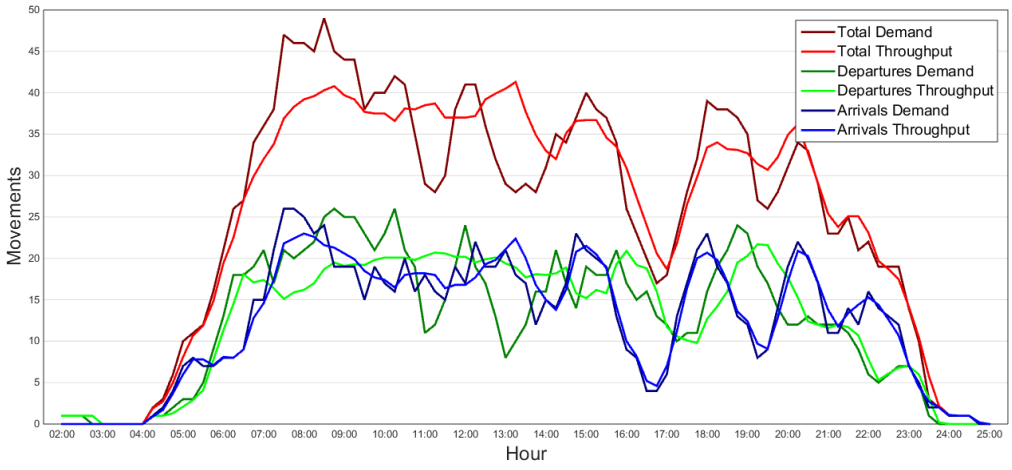
Runway 03 performance is shown in Figure 4. The throughput vs. demand comparison and the average delay results are obtained from a no wind scenario. The maximum throughput achieved is 44 movements per hour, one more than what is achieved in reality (NAV Portugal E.P.E., 2011). This is a normal result due to the operational reality in which air traffic controllers work. It is clear that the throughput is not able to cope with the defined demand, with average departure delays reaching more than eight minutes during the morning demand peak. By breaking down the average delays in Figure 4, it is concluded that the vast majority of the delays come from runway constraints, meaning time aircraft need to wait in order to be allowed to use the runway to either land or takeoff.



a) Runway 21 maximum throughput for different wind conditions



b) Runway 21 average arrival and departure delay for the future demand

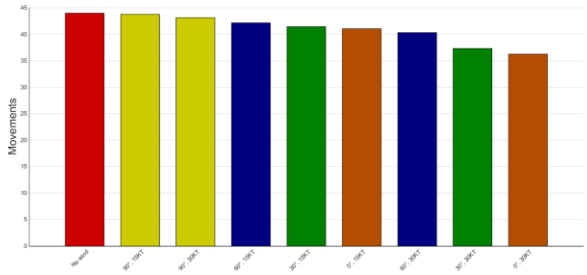


c) Runway 21 throughput vs future demand.

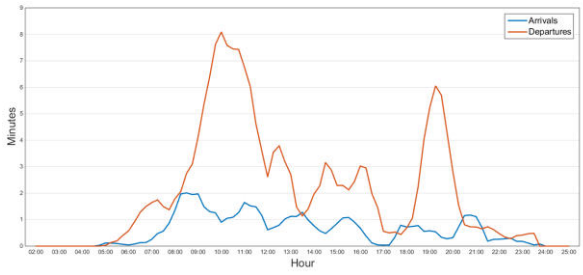
Figure 4: Runway 21 performance.

5.3 Runway 21

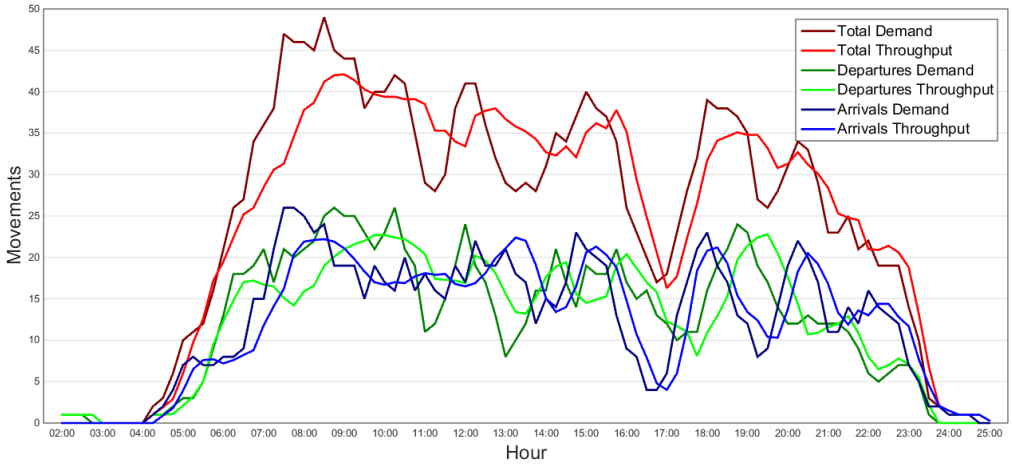
The results for runway 21 are shown in Figure 5. The maximum runway throughput achieved is slightly above 41 movements per hour, again slightly more than what is achieved in reality. The performance of runway 21 is significantly worse than runway 03, with average departure delay surpassing 20 minutes during the morning demand peak. This comes due to the location of runway entry points and runway exits when runway 21 is in use, which result in bigger separations being needed, specially in an Arrival-Departure-Arrival sequence.



b) Runway 03 maximum throughput for different wind conditions



b) Runway 03 average arrival and departure delay for the future demand



c) Runway 03 throughput vs future demand

Figure 5: Runway 03 performance.

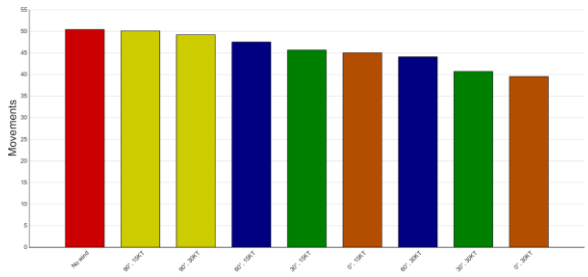
5.4 New Airport Model

Given the results obtained by runway 03 and 21, it is clear that the current airport is not able to accommodate the medium term future demand. Therefore, the need arises to make changes to the current layout and procedures, in order to improve its capacity. As the origins of the bad performance are identified to be runway throughput, this should be the target of further enhancements. The proposed layout modifications can be seen in Figure 6. In order to reduce ROTA, two runway high speed exits, one for each runway, are added at shorter distances from the runway thresholds than the existing ones. The current runway 03 high speed exit is also extended, so that aircraft may use it at higher speeds, which currently is not possible due to the high degree turn that immediately follows it. For runway 21, in order to avoid runway crossings that occupy the runway, limiting its throughput, an extension of the taxiway parallel to the runway is made in order to provide a runway entry point that provides more TODA. When calculating the results, it is optimistically assumed that all aircraft are able to depart from at least the new runway entry point, entirely avoiding runway crossings. With the modifications made, the Arrival-Arrival separation in an Arrival-Departure-Arrival sequence is reduced to 5.5 nautical miles, for both runways. Besides layout modifications, the airspace around the Lisbon Airport is estimated to change, namely military areas, which allows the Departure-Departure separations to be decreased by one minute. This factor is also taken into consideration when calculating the results for the new airport model.

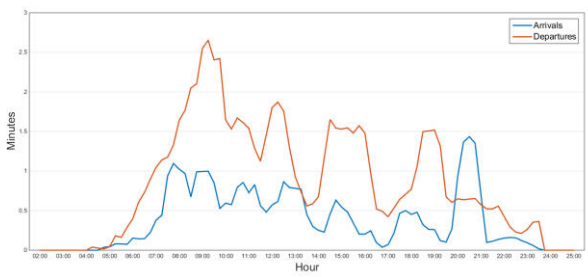


Figure 6: Airfield layout modifications

Figure 7 shows the results of the new model. As they are very similar for both runways in use, only the results for runway 21 are shown. The maximum runway throughput has increased to slightly above 50 movements per hour, bigger than the 48 movements per hour that the future demand has at its highest peak. In consequence, the average departure and arrival delay have significantly decreased. The improvements are overall bigger for runway 21 than for runway 03, as runway 21 had previously a worse performance, and several enhancements are targeted at runway 21. The average departure delay during the demand peak lowered for runway 21 from more than 20 minutes to less than three minutes, the biggest improvement achieved. The average arrival delay is kept bellow one and a half minutes, value that is considered to be acceptable, considering that this represents the time aircraft have to be delayed in the air through lowering speeds or performing holding routes, in order to respect minimum separations.



b) New runway throughput for different wind conditions.



b) New runway 21 average arrival and departure delay.

Figure 7: New airport performance.

6. CONCLUSION

In this work, the current state of the Lisbon Airport is analyzed in detail through the use of computer simulation. *Simmod PLUS!* is used as the simulation tool, and a full model of the airport airfield and surrounding airspace is made.

The current state of the Lisbon Airport is not able to cope with the defined medium term future demand. The runway throughput for both runways in use is not able to accompany the requested demand, specially for runway 21 where the Arrival-Arrival separation in an Arrival-Departure-Arrival sequence is 6.25 nautical miles, 0.25 nautical miles higher than for runway 03. The average departure delays peak at approximately eight and 22 minutes for runway 03 and 21, respectively. Given this results, enhancements to the current airport layout and operational procedures are identified and modeled. With the new layout, Arrival-Arrival separation in an Arrival-Departure-Arrival sequence is reduced to 5.5 nautical miles for both runways, increasing the runway maximum throughput to a value slightly superior to 50 movements, which represents an improvement of approximately six movements for runway 03 and eight movements for runway 21. The average departure delay is greatly reduced for both runways, to values surrounding three minutes, which strengthens the better performance of the new airport model.

The results of this work should be analyzed taking into account the things that are not modeled or not considered by the simulator, such as specific gate attribution to each flight and air traffic controllers work-load both in the approach and in the tower sectors. Besides that, the layout enhancements proposed represent a simple practical way of reducing some current constraints to the airport capacity. They do not take into account all the needed factors in order to actually perform changes to the airport layout, such as the physical characteristics of the terrain or the economical factors.

For further work, it is crucial to further deepen the detail of the model in order to take more influencing factors into consideration. The modeling of the surrounding airspace should be further increased, in order to take into account all the different approach and departure routes and simulate in detail the movement and sequencing of arriving and departing aircraft. The ground movement of aircraft between gates as well as specific gate and slot allocation can as well be further modeled.

In conclusion, the current state of the Lisbon Airport is already working at its maximum capacity and can notsss cope with the medium term future demand. The proposed changes to the airport layout and operational procedures bring improvements to the airport capacity and comfortably accommodate the medium term future demand. However, several factors are not considered by the simulation and this should be taken into account when analyzing the results.

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