NO MORE CONFLICTS: THE DEVELOPMENT OF A GENERIC AIRPORT MODEL IN A SEQUENCE-OPTIMIZATION FRAMEWORK

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ABSTRACT

Components of the airport airside such as runways, taxiways and aprons, have a significant impact in the total capacity of the airport system, where capacity is usually considered as maximum number of air traffic movements or number of passengers accommodated in a given period of time. Operations on the airside impact in the propagation of delay and consequently in the perceived level of service by passengers the terminal buildings. This paper put the focus on the airside operations at airports. A methodology for modelling operations on the ground and the successive optimization is proposed. The methodology presented in this paper is generic enough in the sense that it can be applied to any airport. The objective of this work is to come up with a generic tool that can be used by air traffic controllers in order to minimize conflicts on the ground and consequently increase the airport capacity.

Keywords: Modelling, Optimization, Airport Ground Side, Sliding Window

1. INTRODUCTION

Nowadays, with the constant increase of the air traffic demand, many airports are almost on the edge of their declared capacity. Figures from the previous year show that European flights have increased for the 1.5% in 2015 compared to 2014 (EUROCONROL, 2016). These figures indicate the growth of air traffic, therefore, airports need to be able to accommodate this traffic without incurring in congestion situations, meaning that the capacity of airports needs to be increased. Airport capacity, considered as number of air traffic movements (landings and take offs), is mainly constrained by the runway system (Idris et al., 1998). In this context, the work of the air traffic controllers is to find a good balance between the rate of arrivals and departures in order to ensure safety and the smooth flow of aircraft on the airport airside surface. When priority is given to landings, the apron system is called to accommodate a big amount of aircraft and as a consequence it will release a smaller number of aircraft. Following this strategy, capacity of taxiway and apron system will be particularly exploited, with the risk that, at a certain point, they will not be able to accommodate other aircraft, causing congestion situations. On the other hand, a strategy that prioritizes departures, causes the opposite effect, that is the release of gate capacity and consequently, the increase of queues at the runway holding points.

The research community has widely focused on problems about airside congestion, they came up with new methodologies providing good results. In literature we can find works about the optimization of surface operation where the main objective is to avoid congestion on the ground (Montoya et al. 2010; Simaiakis et al., 2014; Khadilkar and Balakrishnan, 2014). Many of them focused on the scheduling of the take off times in order to optimize the departure flow (Gupta et al. 2009; Rathinam et al., 2009; Pujet et al. 1999; Simaiakis and Balakrishnan 2009; Sandberg et al., 2014; Simaiakis and Balakrishnan 2015). A further objective that is often investigated by the different researchers is related to the reduction of fuel consumption (Simaiakis and Balakrishnan 2009; Simaiakis et al., 2014; Sandberg et al., 2014). Another branch of the research on ground operations focuses on gate assignment problem (Bolat 2000; Dorndorf et al., 2007; Kim and Feron 2012; Narciso and Piera 2015), here the main objectives can be to find the optimum number of gates required to absorb the traffic or to make a robust gate assignment, meaning that the gap between two aircraft using the same gate is maximized.

This work is based on the algorithm proposed in (Liang et al., 2015; Ma 2015) work, where a sliding window approach (Hu and Chen 2005; Zhan et al., 2010; Furini et al., 2015; Toratani et al., 2015) is applied to the sequencing and scheduling of aircraft flows in the airspace. The main contribution of this work is that, it addresses the problem at the airside implementing the aforementioned algorithm. The different problem tackled leads to come up with a different mathematical model that takes into account different decision variables. Moreover, in this work the decisions to be taken are operational so the time frame needs to be short enough to be used as a real-time application. Unlike the previous works done so far, in this paper all the components of the airside such as runway, taxiway and gates are considered together. All the operations that involve these

components are modeled, furthermore, an optimization algorithm is proposed in order to detected and solve all the conflicts. The optimization process was carried out implementing a meta-heuristic, Simulated Annealing (Kirkpatrick et al. 1983), with the objective of detecting and resolving ground conflicts.
This approach can be used for every airport since its general characteristics make it flexible and suitable to different airside configurations. The algorithm is tested using real data from Paris Charles De-Gaulle Airport. The main results are related to number of conflicts detected.

2. METHODOLOGY

In this work a methodology on how to model and optimize ground operation for a generic airport is presented. It is based on the work of (Liang et al., 2015; Ma 2015), and it consist in the implementation of a Sliding Window algorithm together with the use of a meta-heuristic for optimizing ground operations. In figure 1 the main steps of the methodology are shown.

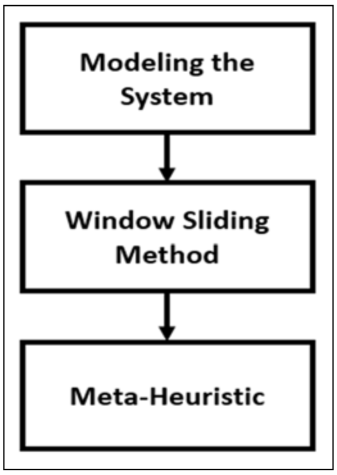

Figure 1: Methodology for modelling and optimizing airport airside operations

The first step consists in the modeling of the system, in other words, which level of abstraction to use to model the different operations. In the second step the optimization model is constructed using a sliding window approach, this approach leads to tackle the problem dynamically and to obtain a more robust solution. In the last step we make use of a metaheuristic, the simulated annealing, in order to solve this N-P Hard optimization problem. The potentiality of this meta-heuristic are described in detail in next section, but in general it allows to find a global optimum searching in the whole state space.

2.1. Modeling the Airport Airside

In the present work the emphasis is put on ground operations. As a first step the airport airside is modelled, with its components. The components that were modelled are listed below:

- Runways
- Taxiways
- Gates

Each one of these components has some generic parameters, in this way, every airport with a different airside configuration can be modelled. For instance, the component "runway" is characterized by the runway name, "taxiway" component is characterized by an entry, an exit and a length and the "gate" component is characterized by a gate number and type. To each one of the components some operations are associated, for example the "runway" component has associated landings and take offs, the "taxiway" component has taxi-in operations and taxi-out operations and the "gate" component has turnaround operations. In figure 3 the objects and their main operations are represented.
In next sections these components and their operations are explained in detail.

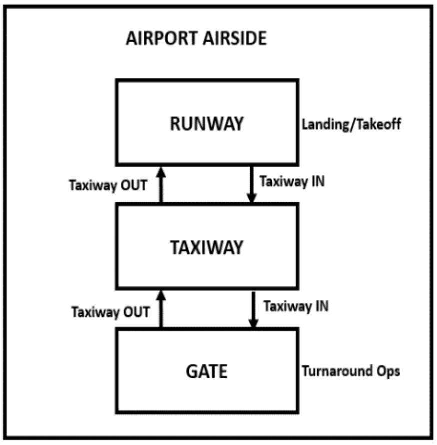

Figure 2: Components of the airside with their main operations

2.1.1. Runway

The runway component is the bottleneck of the airport ground system. Due to safety reasons it can accommodate only one aircraft at a time and even more because separation rules has to put in place based on aircraft ICAO wake turbulence category (WTC) (ref.). Therefore, runway component is mainly characterized by its name. Operations on the runway, like landings and take offs, need to respect separation rules and capacity constraints. Conflicts for this component were evaluated calculating the entry time of the trailing aircraft $T_{In}^{t,r}$ and exit time of the leading aircraft $T_{Out}^{l,r}$ of each aircraft $l, t \in \mathcal{F}$ on the runway $r \in \mathcal{R}$ for a generic operation (landing or take off). If the entry time of the trailing aircraft is less than the exit time of the leading plus the separation minima required $s_{l,t}$ then a conflict is detected (1).

$$R_{l,t}^{r}(\vec{x}) = \begin{cases} 0, T_{Out}^{l,r} + s_{l,t} < T_{In}^{t,r} \\ 1, otherwise \end{cases} \quad (1)$$

where, $R_{l,t}^{r}(x)$ represents the number of conflicts between a trailing and a leading aircraft $l, t \in \mathcal{F}$ on the runway $r \in \mathcal{R}$.

2.1.2. Taxiway

The taxiway network is represented by a set of different available taxiway routes. Each pair runway-gate as a specific taxiway route set available $tw \in TW(r,g)$ where tw is a taxiway route that belongs to the taxiway route set TW(r,g) for every pair runway $r \in \mathcal{R}$ and gate $g \in G$. Each taxiway route is constituted by links and nodes. The choice of taxiway route is a decision variable of the optimization problem. On the taxiway network aircraft have a certain speed and a minimum separation is required between two aircraft. We can identify two different types of taxiway operation, "taxiway in" which is the pattern that leads the aircraft from the landing runway to the gate, and "taxi out", which is the pattern that leads the aircraft from the gate to the departing runway. Conflict on the taxiway routes are detected on links and nodes. Regarding node conflicts they are detected using the same concept for runway conflicts (2).

$$N_{l,t}^{n}(\vec{x}) = \begin{cases} 0, T_{Out}^{l,n} + gs_{l,t} < T_{In}^{t,n} \\ 1, otherwise \end{cases} \quad (2)$$

where, $N_{l,t}^{n}(x)$ is the number of conflicts detected by two aircraft $l,t \in \mathcal{F}$ on the node $n \in \aleph$. A conflict is detected when the entry time for the trailing aircraft $T_{In}^{t,n}$ is less than the exit time of the leading aircraft $T_{Out}^{l,n}$ plus the minimum separation between two aircraft on the ground $gs_{l,t}$. Concerning the conflicts on links, the model makes sure that the aircraft sequence is respected along the links. Conflicts are calculated in the following way (3):

$$L_{l,t}^{me}(\vec{x}) = \begin{cases} 0, D_{l,t}^{me} \geq tg_{l,t} \\ 1, otherwise \end{cases} \quad (3)$$

where, $L_{l,t}^{me}(x)$ is the number of conflicts detected by two aircraft $l,t \in \mathcal{F}$ on the entry link $me \in \mathcal{M}$. In this case a conflicts are detected both at the link entry and link exit $mx \in \mathcal{M}$ every time the distance between two aircraft $D_{l,t}^{me}$ is less than the minimum separation between two aircraft on the taxiway $tg_{l,t}$ with $l,t \in \mathcal{F}$.

2.1.3. Gate

The gate is a parking position for aircraft. In an airport there can be many terminals, and each terminal has some gates where he aircraft can park. At each gate an aircraft undergoes the turnaround operations such as boarding, deboarding, fueling and so on, and then leaves to a new destination. The main parameter associated to the gate component are:

- gate number, which is an identifier of the gate and it is unique,
- gate type, if it is able to host all type of aircraft or only small and medium aircraft.

When an aircraft parks at the gate a "time in" is tracked and then as it leave the gate a "time out" is assigned. In this context, a conflict is detected when for each gate $g \in G$ the "time in" $T_{In}^{f,g}$ for each aircraft $f \in \mathcal{F}$ at a specific gate g, is less than "time out" $T_{out}^{i,g}$ for another aircraft $i \in \mathcal{F}$ and $f \neq i$ at the same gate g (4).

$$G_{f,i}^{g}(\vec{x}) = \begin{cases} 0, T_{In}^{i,g} > T_{out}^{f,g} \\ 1, otherwise \end{cases} \quad (4)$$

The turnaround time for making all the turnaround operation has been estimated as 45 minutes.

2.2. Sliding Window Approach

The Sliding Window method, or Rolling Horizon method, is based on the Receding Horizon Control (RHC) approach. It consist in the evaluation of the system in an extended time horizon, by dividing it in intervals of the same size (windows), and shifting the window using a specific time shift. In each window decisions are made, these decision will affect the decision that will made in the next window. This fact makes this approach to be dynamic. For each aircraft, four different status are identified: Complete, On-Going, Active and Planned. These status depend on the "Time In" and "Time Out" of the aircraft in the system and on the "Starting" and "Ending Time" of the current window. In figure 3 this approach is better explained.

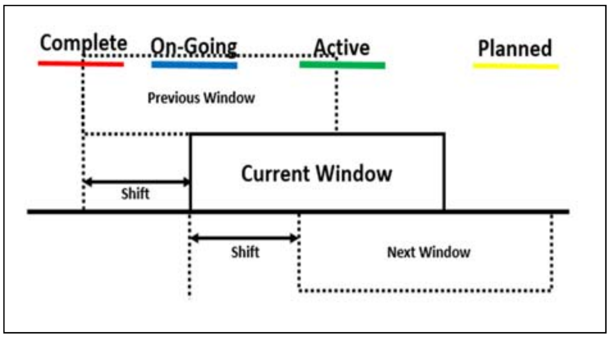

Figure 3: Sliding window approach

For instance, the status "Complete" happens when the aircraft "Time Out" is smaller than the "Starting time" of the current window, the status "Planned" happens when aircraft "Time In" is greater than the "Ending time" of the current window. These two status will not be taken into account when decisions are made. On the other hand, aircraft with the status "On-Going" and "Active" will be taken into account when decisions have to be made, since they are partially or entirely inside the current window.

2.3. Implementation of a Meta-Heuristic

Finally a meta-heuristic can be applied to conduct the optimization process and find an optimal or close to optimal solution. In this work the meta-heuristic Simulated Annealing was applied. Simulated annealing is a local search algorithm, and thanks to his hill-climbing movements it allows to search into the all state space in order to look for a global optimum avoiding to be trapped into a local optimum. It main parameters are temperature T and a cooling schedule. Starting from the temperature T, it generates neighbor solution that are compared with the current one. Every neighbor solution that improves the objective function is accepted, but also solution that degrades the objective function are accepted, and the acceptance rate for them follows a certain probability. In this way the algorithm try to explore all the state space. At each temperature there is a number of transition to be made, and with the cooling schedule the temperature is decreased. Therefore, if the temperature decreases slowly, the algorithm will perform better because it will search in a bigger portion of the state space. At the same time a high temperature requires a greater computational time which might be too long. In the same way higher initial temperatures are recommended as long as they do not affect too much the computational time. So the main parameters to set are the initial temperature, the number of transitions for each temperature and the cooling schedule.

The objective of the optimization process was the resolution of conflicts for every of the object modelled. Conflicts have been explained in detail in the previous section.

The decision variables taken into account for the optimization process are:

- Taxiway-In route, given a set of available routes from the runway to the assigned gate
- Taxiway-Out route, given a set of available routes from the gate to the assigned runway
- Pushback Time, a delay assigned to the aircraft, when it is parked at the gate, before it can start taxi out operations.

The objective of the optimization model is to minimize the objective function that in this case is computed by the number of conflicts detected by the main components of the airside airport that were modelled, runway, taxiway and gate (5).

$$Z(\vec{x}) = \sum_{r\in\mathcal{R}} \sum_{l,t\in\mathcal{F},l\neq t} R^{r}_{l,t}(\vec{x}) + \sum_{n\in\aleph} \sum_{l,t\in\mathcal{F},l\neq t} N^{n}_{l,t}(\vec{x}) + \sum_{n\in\aleph} \sum_{l,t\in\mathcal{F},l\neq t} (L^{me}_{l,t}(\vec{x}) + L^{mx}_{l,t}(\vec{x})) + \sum_{g\in G} \sum_{f,i\in\mathcal{F},f\neq i} G^{g}_{f,i}(\vec{x}) \quad (5)$$

3. SCENARIO AND RESULTS

In order to test the potentiality of the methodology it was taken as a case study Paris Charles de Gaulle Airport. As a first stage of the research, it was not modelled the entire ground surface, but only two of the four runways and one of the three terminal that constitutes the entire airport airside. In Figure 4 there is a representation of the portion of airside modelled in this work.

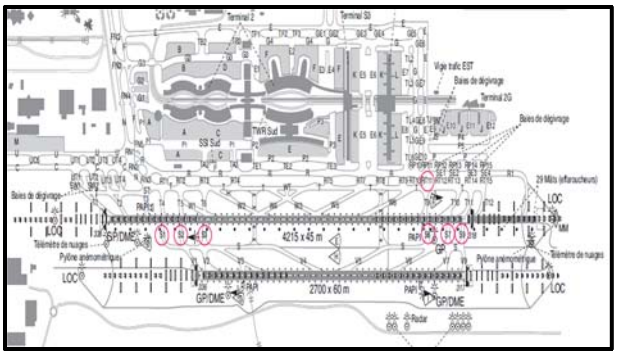

Figure 4: Part of the airside modelled of Paris Charles de Gaulle Airport

In table I all the main characteristics of the airside components are listed, whereas in table II shows the main parameters of the sliding window and the simulated annealing.

Table I: Airside components characteristics

Number of Runway	2 (one for landing and one for departures)
Taxiway network	336 taxiway routes set
Number of Gates	168

Table II: main parameters of the sliding window and simulated annealing

Sliding window method	
Window length	30 min
Shift	5 min
Simulated annealing	
Initial Temperature	Increasing the temperature until the acceptance rate of neighbor solutions reaches the 80%
Transitions	200
Cooling schedule	α=0.95, $T_{i+1} = T_i x\alpha$

3.1. Scenario

A timeframe of two hours of a specific day of operations in Paris Charles de Gaulle Airport was tested. It was chosen the peak time of the time from 6:00 A.M. to 8:00 A.M. In total there are 58 air traffic movements split in 22 arrivals and 36 departures.

3.2. Results

After running the optimization mode we obtained results about conflicts related to the airside components. We run first the optimization model without the use of the simulated annealing algorithm and then implementing it. In tables III and IV the results are shown.

Table III: results scenario without the implementation of the algorithm

Scenario without the implementation of the algorithm		
Computational time		44.326 sec.
Runway conflicts		45
Taxiway conflicts	links	0
	nodes	0
Gate conflicts		0

Table IV: results scenario with the implementation of the algorithm

Scenario with the implementation the algorithm		
Computational time		50,314 sec,
Runway conflicts		31
Taxiway conflicts	links	0
	nodes	0
Gate conflicts		0

In the scenario without the implementation of the algorithm there are 45 conflicts detected on the runway and 0 for the other components. In the scenario where the algorithm is implemented the number of conflicts is 30 and 0 for the other components. Looking at these results it can be seen that the algorithm improves the initial solution by 34%. Nevertheless, it does not give a conflict free solution.

4. CONCLUSIONS

In the methodology presented in this paper, the airport airside is modelled. The approach employed allows to obtain a high level of flexibility and abstraction that permits to model any airport airside. Furthermore, with the implementation of a sliding window algorithm and the use of simulated annealing meta-heuristic, we aimed at resolving conflicts for the airside components. Preliminary results show that the initial solution is improved with the use of this methodology, although not all conflicts have been solved. The solution that was found was tested in a time frame of two hours and it was achieved in 50,314 seconds, which makes this methodology able to be used in a dynamical environment where decision has to be taken in real time. The proposed methodology can be a very useful tool, when operational decisions have to be made for ground operations. The algorithm implementation needs further refinements in order to give a free conflict solution, this could be achieved tuning the sliding window parameters and the simulated annealing parameters. In the future would be good to compare the same methodology by using a different meta-heuristic and moreover introduce simulation approaches to test the feasibility of the optimized solution.

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