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TOWARDS INTEGRATED PLANNING OF GROUND PROCESSING OF AIRCRAFT AT AIRPORTS

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ABSTRACT

In this article, is considered the management of aircraft at airports, at arrival, parking and departure. This management is composed of different subprocesses tackled collaboratively by different airport stakeholders. To these subprocesses are attached different decision problems which are interdependent in time and space. Among these interdependencies is studied more particularly at the level of daily planning. the one between the Aircraft Gate Assignment Problem and the Ground Handling Resource Allocation Problem which have been until today treated separately. The opportunity to build a global framework to cope simultaneously, and more efficiently, with these two problems is considered particularly, given the increasing flexibility of ground handling operations resulting from automation. The case of long-haul flights associated with dedicated apron/gate areas is particularly motivating.

Keywords: Integrated Ground Operations, Airport Ground Handling, Aircraft Gate Assignment, Scheduling, Optimization.

GENERATIVE AI USAGE STATEMENT: This research did not use generative AI.

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1 INTRODUCTION

Airside ground operations refer to the activities and functions that take place in the secure area of an airport, where aircraft move between the runways and parking areas upon arrival and departure via taxiways, are then unloaded, loaded and refueled in order to be prepared for departure. Airside operations, involving pre-tactical and tactical coordination between the various stakeholders, including airlines, ground handling companies, air traffic control and airport authorities, seeks to meet the objectives of safety and operational efficiency from both the operators' and users' perspectives. Today a well-recognized approach to deal with tactical coordination is the Airport Collaborative Decision Making (A-CDM) (CANSO 2023).

The assignment of boarding gates to arriving, and eventually departing flights, or AGAP (Aircraft Gate Assignment Problem), plays an important role given its impact on the efficiency of flight operations, both in terms of airline operational costs and airport performance. It has been considered that AGAP is strongly linked to the problem of choosing the route followed by aircraft in the airport taxiway network, the TAP (Taxiing Assignment Problem), between runways and parking areas. So, while many studies have been developed to treat of diverse formulations of the sole AGAP problem, a significant number of publications deal simultaneously with AGAP (Bouras et al. 2014, Das et al. 2020) and TAP (Long et al. 2017). The solution of the AGAP problem, when implemented, also has an impact on the passenger experience, as these gates constitute an interface between the aircraft and the passenger terminal, then many studies about the AGAP adopt as optimality criterion a measure of the passengers 'satisfaction, such as the total passengers walking distance. Appropriate gate assignment should then facilitate boardings and connections between flights by reducing travel distances for travelers within terminals, which contributes to on-time departures. A wide range of resolution techniques ranging from exact methods, but unable to handle real-size AGAPs (hundreds of flights and tens of gates), to heuristics and metaheuristics producing approximate solutions and associated with artificial intelligence techniques, have been proposed in the literature.

Ground handling (GH) considers the activities taking place at and around parked aircraft. They are in charge of processing passengers, cargo, facilities and supplies after arrival or before departure of aircraft. Ground handling is an important enabler for efficient airport operation and further contributes to avoid traffic perturbations, then easing air traffic management. The operation of this system involves many global operators (airports, airlines, Air Traffic Control (ATC), Air Traffic Management (ATM)) and local operators (ground handlers, local suppliers, safety operators…) actors, whose tight coordination is essential. Most of ground handling operations are performed by using fixed facilities at parking positions and a large variety of vehicles to carry luggage, cargo, products and equipment. These Ground Support Equipment (GSE) are in general specific to each type of operation. To achieve ground handling efficiency considering the avoidance of delayed operations and the minimization of operations costs, energy costs and environment impact, the scheduling of these resources is also an important issue. Several direct studies to solve the scheduling problem associated to ground handling have been performed (Padrón & Guimarans, 2019), (Zhang et al., 2022). In general, in these studies, a global scheduling problem is formulated and ad hoc solution methods are proposed. Exact solutions are scarcely obtained and their implementation, which implies a permanent interaction between different actors, is difficult. The problem of sizing and locating technical and human resources for ground handling operations at the pre-tactical level, the Ground Handling Resource Allocation Problem (GHRAP) has been studied very little, which has led to a multiplication of ground handling resources at the aprons and parking areas, sometimes with very low utilization rates.

Until today, the AGAP and GHRAP problems have been treated separately in the literature. This can be explained by the presence of different stakeholder for these two problems and the lack of flexibility in sharing conventional ground handling resources. However, today with a tendency towards automation of operations carried out using mainly ground service equipment (GSE) (Alonso-

Tabares and Mora-Camino, 2019), a more rational use of these, both in nominal (pre-tactical) and disturbed (tactical) traffic situations seems to become possible. This is the question that is examined in this publication. The methodological approach followed here is to first consider a standard mathematical formulation of each of the two problems, then to analyze the constraints that each of them exerts on the other, then to formulate a common objective and to gather their constraints in order to formulate a global problem whose resolution will be analyzed whole possible benefits of this integration approach must be discussed.

The main body of the paper is organized as follows: in section 2, the AGAP is discussed further and a mathematical formulation is proposed, in section 3, the ground handling operations around an aircraft are briefly described and a corresponding mathematical formulation is proposed, in section 4, a global formulation of the joint AGAP-GHRAP is introduced and discussed, in section 4 the case of long-haul flights associated with dedicated apron/gate areas is considered and finally, preliminary conclusions are presented.

2 ASSUMPTIONS ABOUT THE AIRCRAFT GROUND OPERATIONS

Aircrafts transiting through an airport use its facilities (runways, taxiways, maneuvering areas and parking stands) as well as a whole series of equipment (guidance and ground handling). In order to guarantee an efficient operation, it is necessary to make these facilities and equipment available to them, without waiting time and in the best possible conditions. Thus, the allocation of boarding gates (AGAP) to aircraft arriving and departing from an airport is an operational problem that has important consequences for passenger comfort and the operational efficiency of the airport.



Photo 1: Ramp and remote gates at Vienna airport. Source: Authors.

We consider here the classical case of an airport and dedicated terminals with either ramp gates connected to the passenger terminals or gates at remote positions. In general, the gates at remote position have no permanent equipment (stairs or ramp). It is supposed that all aircraft can be assigned to remote gates while to each aircraft type is attached a set of ramp gates which it can use.

In this study, we place ourselves at the tactical level where at the beginning of the day a set of flights are planned for departure and arrival. It is assumed that ATC manages a balanced and traffic and that weather conditions remain stable during the period considered, which makes it possible to anticipate which runways each aircraft will use for landing or takeoff. Each arriving aircraft moves along a taxiway to an available gate which it will occupy until departure time. Then according to the assigned gates to the flights, the characteristics (length and duration) of paths for arrival taxiing and departure taxiing of each aircraft can be estimated.

For all arriving aircraft are known the planned landing times (PLDT) and for departing aircraft, their planned off block time (POBT) where here is followed the terminology used by A-CDM. Here we suppose that an aircraft assigned to a gate at arrival will depart from that one for its next flight.

Then, it is possible to compute the time window available to perform ground handling activities around each parked aircraft.

Passengers and the load carried by the arriving aircraft are either, in transit to another flight, or intended to leave the airport using a means of ground transport. In cases where the airport layout allows minimizing the distances traveled by these transit passengers, and in the case where an internal mobility service on the ground side of the airport limits the negative effects of transfers over long distances, the objective of the AGAP problem can be limited to the minimization the operating cost of aircraft on the airport platform. In the case where it is necessary to take into account passenger movements, a passenger comfort criterion can take into account the discomfort of walking inside the passenger terminals.

With respect to ground handling, in this study, among many possible organizations of ground handling, is considered a particular organization which is described here. It is assumed that ground handling activities on arrival as on departure, can take place simultaneously and have a duration that depends on the flight (number of passengers and cargo size) and the type of aircraft, this so as not to go into too much detail at the tactical level. Ground handling equipment is subdivided between those that are permanently attached to each gate (ramp, access to external electrical sources and water) and those that are mobile, the ground service equipment (GSE), and that are shared between the different aircraft at parking positions. It is assumed that ground handling equipment are grouped by type on different platforms where they are re-energized and stored until assignment to the corresponding ground handling activity on a new aircraft on arrival or departure. It is assumed here that, given the large size of many airport parking areas, several specialized bases of the same type of GSE can be located nearby. It is assumed here that their location is already fixed, as well as the size of the GSE fleets using them. It will be assumed that each GSE that carries out a GH activity at an aircraft, returns to its base before carrying out a new mission. Furthermore, we assume that the management of each GSE fleet executing elementary GH activities of a given type is performed independently of the others. This leads to treating independently for each type of GSE, a problem of assigning fleets to GH tasks with time window constraints.

3 MATHEMATICAL FORMULATION OF THE AGAP

Many publications about the management of ground traffic at airports consider the flight Gate assignment problem (FGAP) whose focus is on service to travelers and leave in fact the technical aspects related to the aircraft that carry out these flights in the background. The mathematical formulation proposed here not only takes into account the service offered to passengers but also considers the constraints to which the aircraft are subjected during their stopover. Behind the assignment of a flight to a gate, it is indeed an aircraft that will find itself positioned there between two flights.

The parameters of the assignment problem are described below, they are composed of integer numbers, discrete sets and real positive numbers (delays and distances):

N_A is the number of arriving flights and N_D is the number of departing flights departed from the airport during the planning day;

T is the duration of the planning period;

A_c is the set of aircraft processed during the planning period;

$n_A(i_A)$ is the index of the aircraft of arriving flight i_A and $n_D(i_D)$ is the index of departing flight i_D. $i_D = F(i_A)$ is the index of departing flight with aircraft $n_A(i_A)$, so, $n_D\left(FF(i_A)\right) = n_A(i_A)$.

Let $F_c(i)$ be the set of flights in correspondence with flight i.

M is the total number of gates with $M = M_T + M_R$, where M_T is the number of gates at passenger terminals and M_R is the number of remote gates.

$G(n_A(i_A))$ is the set of gates that can be used by aircraft $n_A(i_A)$.

π_i^A is the number of passengers of arriving flight i and π_i^D is the number of passengers of departing flight i;

p_i^A is the number of passengers of flight i arriving at destination, i=1 to N_A;

p_i^D is the number of passengers starting travel with flight *i*, *i*=1 to N_D;
p_{ir}^T is the number of passengers transferring from flight *i* to flight *r*, *i*=1 to N_A, *r*= 1 to N_D;
w_j^A is the walking distance between gate *j* and baggage claim area;
w_j^D is the walking distance between check-in area and gate *j*;
w_{jk} is the walking distance between gate *j* and gate *k*;
t_{jk} is the mean delay between gate *j* and gate *k*, in the case of a remote gate, this includes the transport between the passenger terminal and the remote gate.
d_{jl}^T is a time-margin to cover delays to disembark at gate *j* and to board at gate *l*;
d_{ej}^A is the taxiway distance between exit *e* of runway and gate *j*;
t_{ej}^A is the mean taxi delay between exit *e* of runway and gate *j*;
d_{je}^D is the taxiway distance between gate *j* and runway entry *e*;
g_{ij}^A is the duration of ground handling activities at arrival of flight *i* at gate *j* and g_{rj}^D is the duration of ground handling activities at departure of flight *r* from gate *j*; these durations depend of the type of aircraft and GH equipment as well as of the passenger and cargo load to be embarked or disembarked.

Adopting X_{ij} as a binary decision variable, equal to 1 if and only if flight *i* is assigned to gate *j*, 0 otherwise, different performance indexes can be expressed:

The total distance traveled is given by:

$$TDT = \sum_{j=1}^{M_T}\sum_{i=1}^{N_A} p_i^A \cdot w_j^A \cdot X_{ij} + \sum_{j=M_T+1}^{M_T+M_R}\sum_{i=1}^{N_D} p_i^D \cdot w_j^D \cdot X_{ij} + \sum_{j=1}^{M_T+M_R}\sum_{k=1,k\neq j}^{M_T+M_R}\sum_{i=1}^{N_A}\sum_{r=1}^{N_D} p_{ir}^T \cdot w_{jk} \cdot X_{ij} \cdot X_{rk} \quad (1)$$

The total flow of passengers transported between the terminals and the remote gates is given by:

$$TFT = \sum_{j=M_T+1}^{M_T+M_R}\left(\sum_{i=1}^{N_A} \pi_i^A \cdot X_{ij} + \sum_{r=1}^{N_D} \pi_i^D \cdot X_{rj}\right) \quad (2)$$

The total taxi distance of aircraft is given by:

$$TTD = \sum_{i=1}^{N_A}\sum_{j=1}^{M_T+M_R} d_{ej}^A \cdot Y_{ie} \cdot X_{ij} + \sum_{r=1}^{N_D}\sum_{j=1}^{M_T+M_R} d_{je}^D \cdot Z_{re} \cdot X_{rj} \quad (3)$$

Here $Y_{ie} = 1$ if runway exit *e* is assigned to arriving flight *i*, $Y_{ie} = 0$ otherwise and $Z_{rs} = 1$ if runway entry *s* is assigned to departing flight *r*, $Y_{rs} = 0$ otherwise. We have necessarily:

$$\sum_{e\in E} Y_{ie} = 1 \quad 1 \le i \le N_A \text{ and } \sum_{s\in S} Y_{rs} = 1 \quad 1 \le i \le N_D \quad (4)$$

where *E* is the set of runways exits and *S* is the set of runways entries. Note that choosing a runway exit for an arriving aircraft informs the selected landing runway while choosing a runway entry informs the selected take-off runway for a departing aircraft. Observe also that, the Y_{ie} and Y_{rs} are operational parameters to be set by Air Traffic Control.
The gate assignment must satisfy the following assignment constraints:

$$\sum_{j\in G(n_A(i))} X_{ij} = 1 \quad 1 \le i \le N_A \quad \text{and} \quad \sum_{j\in G(n_D(i))} X_{ij} = 1 \quad 1 \le i \le N_D \quad (5)$$

$$\sum_{j\in G(n_A(i))} X_{ij} \cdot X_{FF(i)j} = 1 \quad 1 \le i \le N_A \tag{6}$$

Constraints (5) express the necessity that every flight must be assigned to one and only one gate while constraints (6) express that if a gate is assigned to an arriving flight, the next flight using the same aircraft will start from the same gate. The planned in-block time of flight *i*, *PIBT*(*i*) is such as:

$$PIBT(i) = PLDT(i) + \sum_{j\in G(n_A(i))} \sum_{e\in E} t^A_{ej} \cdot Y_{ie} \cdot X_{ij} \quad 1 \le i \le N_A \tag{7}$$

where $PLDT(i)$ is an exogenous variable. Then the planned off-block time of flight $FF(i)$, *POBT*(*FF*(*i*)) must be such as:

$$POBT(FF(i)) \ge PIBT(i) + \sum_{j\in G(n_A(i))} \left(g^A_{ij} + g^D_{FF(i)j}\right) \cdot X_{ij} \quad 1 \le i \le N_A \tag{8}$$

To ensure correspondences between an arriving aircraft and others, the following constraints must be satisfied:

$$PIBT(i) + \sum_{j\in G(n_A(i))} \sum_{l\in G(n_D(k))} (t^A_{jl} + d^T_{jl}) \cdot X_{ij} \cdot X_{kl} \le POBT(k) \quad k \in F_c(i) \quad 1 \le i \le N_A \tag{9}$$

To avoid overlapping of flights at a gate, an additional binary variable is introduced: O_{irj}, $i = 1\ to\ N_A, r = 1\ to\ N_A$, $j \in G\left(n_A(i)\right), j \in G(n_A(r))$: $O_{irj} = 1$ if $X_{ij} \cdot X_{rj} = 1$ and flight *i* is assigned to gate *j* before flight *r*, otherwise $O_{irj} = 0$. Then we have the constraints:

$$POBT(i) \le PIBT(r) + V \cdot (1 - O_{irj}) \quad j \in G\left(n_A(i)\right),\ j \in G(n_A(r)) \tag{10}$$

where *V* is a very large positive number.

Then, choosing one of the performance indexes given by (1), (2) or (3), or a composition of them as objective and considering constraints (4) to (10), we get an instance of the formulation of the AGAP problem. This problem is a combinatorial (Binary) optimization problem and an approximation of its solution in real cases should be obtained using intensive computing techniques such as metaheuristics and AI based techniques.

Observe that the solution will provide useful ground traffic information (demand of traffic in runways and taxiways) through the variables Y_{ie} and Z_{re} and also a valuable information for the ground handling operations since, under the flight assignment appears the aircraft assignment to the gates with the volumes of activities g^A_{ij} and g^D_{rj}, with the timings *PIBT*(*i*) and *POBT*(*i*).

4 THE GROUND HANDLING RESOURCE ALLOCATION PROBLEM

Here it is considered that the GSEs that perform the same GH activity *a* on parked aircraft are attached to K_a different bases. The allocation problem consists of assigning the GSEs from the K_a bases to perform GH activity *a* on each arriving or departing aircraft parked at the ramp and remote gates, the objective being for example to minimize the travelled distances by this type of GSE. The solution of the AGAP problem provides for each gate the succession of tasks of type *a* that must be performed there. The adopted notations are the following:

$A^+$and $A^-$are respectively the set of GH type of tasks that must be performed on an arriving or departing aircraft, with $A = A^+ \cup A^-$.

$J^a_j$is the set of m^a_jtasks of type *a* to be performed at gate *j*, these tasks are ordered in ascending chronological order;

G^a_k is the number of GSE of type *a*, attached to base *k*, $1 \le k \le K_a$;

r^t_{ja} and s^t_{ja} are respectively the planned start and end the t^{th} tasks of type *a* at gate *j*, $0 \le t \le m^a_j$;

δ^+_{kj} and δ^-_{kj} are respectively the distance from/to the k^{th} base, to/from the j^{th} gate;

θ^+_{kj} and θ^-_{kj} are respectively the delays from/to the k^{th} base, to/from the j^{th} gate;

γ_j^{at} is the number of tasks of type a to be performed at the t^{th} GH at gate j;
ρ_{kja}^t and σ_{kja}^t are respectively the planned start and end for the t^{th} tasks of type a at gate j for a GSE attached to base k;
τ_{ja}^{t+} and τ_{ja}^{t-} are respectively time buffers to start/finish tasks a with an arriving/departing aircraft at gate j;
g_{ja}^t is the duration of the t^{th} tasks of type a at gate j;
$n_j^F(t)$ and $n_j^A(t)$, $0 \leq t \leq m_j^a$, are respectively the indexes of the t^{th} flight and t^{th} aircraft performing GH at gate j;

If the t^{th} task of type a at gate j corresponds to an arriving aircraft (see Figure 1), we have:

$$r_{ja}^t = PIBT\left(n_j^F(t)\right) + \tau_{ja}^{t+} \qquad s_{ja}^t = r_{ja}^t + g_{ja}^t \tag{11}$$

$$\rho_{kja}^t = PIBT\left(n_j^F(t)\right) - \theta_{kj}^+ \qquad \sigma_{kja}^t = s_{ja}^t + \theta_{kj}^- \tag{12}$$

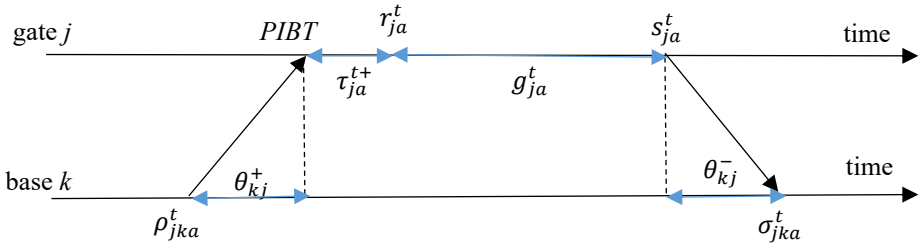


Figure 1 Timing from base *k* to gate *j* for task *t* of type *a* at arriving aircraft

If the t^{th} task of type a at gate j corresponds to a departing aircraft (see Figure 2), we have:

$$r_{ja}^t = POBT\left(n_j^F(t)\right) - \tau_{ja}^{t-} - g_{ja}^t \qquad s_{ja}^t = r_{ja}^t + g_{ja}^t \tag{13}$$

$$\rho_{kja}^t = r_{ja}^t - \theta_{kj}^+ \qquad \sigma_{kja}^t = s_{ja}^t + \theta_{kj}^- \tag{14}$$

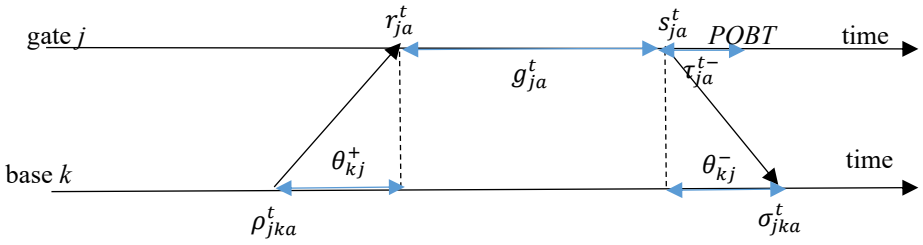


Figure 2 Timing from base *k* to gate *j* for task *t* of type *a* at departing aircraft

Observe that for GH be feasible with the planned PLNT and POBT for aircraft $n_j^A(t)$, we must have:

$$PIBT\left(n_j^F(t)\right) + \max_{a \in A^+}\{\tau_{ja}^{t+} + g_{ja}^t\} \leq POBT\left(n_j^F(t)\right) - \max_{a \in A^-}\{\tau_{ja}^{t-} + g_{ja}^t\} \tag{15}$$

Let x_{km}^{jat}=1 when the m^{th} GSE of the k^{th} base of type a is assigned to perform the tth GH operation of type a at gate j, and $x_{km}^{jat} = 0$ otherwise.

The following conditions must be satisfied by the assignment of the fleet of GSE of type a:

$$\sum_{k=1}^{K_a}\sum_{m=1}^{G_k^a} x_{km}^{jat} = \gamma_j^{at} \quad \text{for } 0 \le t \le m_j^a,\ 1 \le j \le M,\ a \in A \tag{16}$$

and when for $k \in \{1, \cdots, K_a\}$ and $m \in \{1, \cdots, G_k^a\}$:

$$\begin{gathered}\text{if } x_{km}^{jat} = x_{km}^{j'at'} = 1 \text{ with } j \neq j' \text{or } t \neq t' \text{ with } \rho_{ja}^{t} < \rho_{j'a}^{t'} \\ \text{then } \sigma_{kja}^{t} \le \rho_{j'a}^{t'} \text{ for } 0 \le t \le m_j^a, 0 \le t' \le m_{j'}^a,\ 1 \le j, j' \le M,\ a \in A\end{gathered} \tag{17}$$

Constraints (16) implies that the demand of GH service with respect to task a is satisfied and constraints (17) avoids the assignment of overlapping tasks to a same GSE.

The total distance traveled by the GSE of all types can be a measure of performance of a feasible assignment of the GSE fleets to the GH activities of the considered period. It is given by:

$$TDT = \sum_{j=1}^{M}\sum_{a\in A}\sum_{k=1}^{K_a}\sum_{m=1}^{G_k^a}\sum_{t=1}^{m_j^a}\left(\delta_{kj}^{+} + \delta_{kj}^{-}\right)\cdot x_{km}^{jat} \tag{18}$$

Then the minimization of TDT taking into account constraints (16) and (17) compose the GHRAP which is also a combinatorial (Binary) optimization problem. Once the solution of this optimization problem has obtained, different performance indexes of interest for the sizing of the GSE fleets and positioning of the bases can be computed:

- α_{GSE}^{ka} : The utilization rate in % of the GSEs of type a at the k^{th} base is given:

$$\alpha_{GSE}^{ka} = 100 \cdot \sum_{j=1}^{M}\sum_{m=1}^{G_k^a}\sum_{t=1}^{m_j^a}\left(\sigma_{jka}^{t} - \rho_{jka}^{t}\right)\cdot x_{km}^{jat} / (G_k^a \cdot T) \quad \text{for} \quad k \in \{1, \cdots, K_a\}, a \in A \tag{19}$$

- α_{GSE}^{a}: The utilization rate of the GSEs of type a during the planning period:

$$\alpha_{GSE}^{a} = 100 \cdot \sum_{j=1}^{M}\sum_{k=1}^{K_a}\sum_{m=1}^{G_k^a}\sum_{t=1}^{m_j^a}\left(\sigma_{jka}^{t} - \rho_{jka}^{t}\right)\cdot x_{km}^{jat} / \left(T \cdot \sum_{k=1}^{K_a} G_k^a\right) \quad \text{for} \quad a \in A \tag{20}$$

- The global rate of utilization of the GSEs dedicated to GH during the planning period:

$$\alpha_{GSE} = 100 \cdot \sum_{j=1}^{M}\sum_{a\in A}\sum_{k=1}^{K_a}\sum_{m=1}^{G_k^a}\sum_{t=1}^{m_j^a}\left(\sigma_{jka}^{t} - \rho_{jka}^{t}\right)\cdot x_{km}^{jat} / \left(T \cdot \sum_{a\in A}\sum_{k=1}^{K_a} G_k^a\right) \tag{21}$$

5 INTEGRATED FORMULATION OF GROUND PROCESSING OF AIRCRAFT

In the two previous sections, we introduced the mathematical formulations of the AGAP and GHRAP problems independently, although these two problems are interdependent. In order to establish the AGAP, it was assumed that on the GH side, everything required of it can be achieved within the standard time limits. This, in fact, implicitly assumes that every gate is equipped with all the GH equipment associated with its stand type. This would then lead to a plethora of equipment and, outside of peak traffic hours, to widespread underutilization. This approach seems inevitable in the case of gates in a hub associated with high-rotation domestic traffic, but in the case of long-haul intercontinental flights, it is not uncommon to see an aircraft parked for hours between its arrival at the gate and its departure, and in this case, it seems that there is room for sharing mobile GH equipment such as GSEs between the gates. This approach leads to additional investment costs in mobile equipment, while the AGAP solution does not take into account the GH operational costs it induces. Regarding operational costs, it is difficult to compare, for example, a solution associated with gates containing all their necessary GH mobile equipment and a solution, as developed in the previous section, comprising specialized bases and shared equipment: much will depend on the layout of the aircraft parking

and GSE traffic areas, but also on the equipment maintenance procedures. In the case where the two problems are treated separately, the AGAP solution could lead to considering a GHRAP problem that has no feasible solution, while the joint consideration of the two problems could still present feasible solutions for the GH and lead to an optimal global solution. However, in the case where even the joint problem has no feasible solution, the partial implementation of the AGAP solution would lead to cascading delays for departing flights, and it would be necessary to review the airport's service offering. This service offering, in addition to the runways and adjoining taxiways, consists of aircraft parking gates and GH resources. Here too, one can expect that a global approach, consisting simultaneously of redeploying parking gates and resizing and relocating GSE bases, would be much more efficient than a two-step solution where the second would fill the deficiencies of the first. A first integrated formulation of the two allocation problems, the Aircraft Gate and Ground Handling Assignment Problem (AG^{2}HAP), can be constructed as follows:

1) The joint consideration of the decision (Binary) variables of the two problems:

$$X_{ij},\ x_{km}^{jat},\quad 1 \le i \le N_A\ ,\ 0 \le t \le m_j^a, 0 \le t' \le m_{j'}^a\ \ 1 \le j \le M,\ \ a \in A \tag{22}$$

2) The constitution of a global optimality criterion by weighting the optimality criteria of each of the original problems. For example, one could consider a criterion related to the total energy consumption of aircraft on the ground and GSEs performing GH during the planned period. In this case, an initial global optimization criterion would be:

$$C = w_{a/c} \cdot TTD + w_{GSE} \cdot TDT \tag{23}$$

where $w_{a/c}$and w_{GSE} are respectively conversion coefficients of travelled distance to spent energy for taxiing aircraft and GSEs. In (22) *TTD* is given by relation (3), while now *TDT* is now written:

$$TDT = \sum_{i=1}^{N}\sum_{j=1}^{M} X_{ij} \cdot \left(\sum_{a\in A}\sum_{k=1}^{K_a}\sum_{m=1}^{G_k^a}\sum_{t=1}^{m_j^a}\left(\delta_{kj}^{+} + \delta_{kj}^{-}\right) \cdot x_{km}^{jat}\right) \tag{24}$$

This formulation could be made more relevant by taking into account the types of aircraft and GSEs used, as well as their movement and waiting phases.

3) By considering simultaneously constraints (4) to (10) and (16) and (17).

The global problem obtained is a mega optimization problem that can be solved today satisfactorily by combining, for example, meta-heuristics (Ezugwu et al. 2021) with decomposition techniques (Rahmaniani et al. 2017) where the GHRAP becomes a sub-problem to be solved repetitively until the global solution is obtained.

6 CONCLUSION

This paper has shown that it is possible to simultaneously design and formulate the AGAP and GHRAP problems at the tactical level, leading to the AG^{2}HAP, which should, in many cases, produce more balanced solutions regarding the different operators present at the airport (airlines and GH operators). In cases where the taxiway layout is sufficiently complex to raise a taxiway selection problem, this appears to be integrable into the approach proposed here.

Even before implementing traffic solutions on the airport platform, AG^{2}HAP can be used to evaluate different organizations and locations of parking gates, fleets, and vehicle bases, allowing for better exploitation of the opportunities offered by the increasing automation of GH activities.

The challenge of translating this approach online can follow the approach proposed in (Alonso-Tabares et al., 2021), where the AG2HAP problem would be treated iteratively over a rolling horizon to incorporate the effect of disruptions.

Much remains to be done to finalize this approach, this will notably involve developing efficient algorithms for solving AG2HAP for instances of significant size of the problem.

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