Towards a decision support tool for airport slot allocation: an application to Guarulhos (Sao Paulo, Brazil)

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1. Introduction

In the vast majority of airports in which demand significantly exceeds capacity, the allocation of slots is performed according to IATA's Worldwide Slot Guidelines (WSG); see IATA (2017) and Ribeiro et al. (2019). The slot allocation process prescribed in the WSG is conducted bi-annually (for the winter and summer seasons) by schedule coordinators appointed by transport authorities, and involves several stages until the final slot allocation is achieved. The focus of this paper is placed on the most important stage of this process: initial slot allocation. This is when, considering the capacities declared by airports, the coordinators first decide whether the slot requests made by airlines are accepted, or need to be displaced or even rejected. At this stage, only series of slots – slots for the same flight on the same day of the week requested for at least five times over a season – are at stake.

Schedule coordinators typically perform the initial slot allocation using heuristic approaches with the support of software packages such as PDC SCORE or T-Systems SAMS. These packages are certainly helpful, but do not offer optimization capabilities, and therefore may lead to slot allocations that are not efficient. Recently, several models have been proposed in the literature that offer such capabilities (e.g., Zografos et al. 2012 and Ribeiro et al. 2018). This is in particular the case with PSAM, the optimization model presented in Ribeiro et al. (2018). It fully complies with the WSG, and has been shown to provide slot allocations clearly better than the ones coordinators have implemented in several airports with respect to two key criteria: total displacement (i.e., the sum of the differences between the requested time and the allocated time for all the slots requested) and maximum displacement (i.e., the maximum such difference).

In this paper, we introduce a decision-support tool based on PSAM aimed to assist schedule coordinators in their initial slot allocation decisions. This tool can be applied to identify efficient slot allocations considering all criteria (primary and additional) specified in the WSG, as well as to assess the solutions obtained by schedule coordinators through their heuristic approaches. It relies on several techniques for generating, evaluating, visualizing, and ranking solutions. The application of the tool is illustrated for the busiest airport in South America – Guarulhos (GRU), Sao Paulo, Brazil.

2. Slot allocation criteria

According to the WSG, the allocation of (series of) slots is performed according to primary and additional criteria. The primary criteria distinguish four types of slot requests: historic, change-to-historic, new-entrant, and other. These primary criteria are straightforward to apply. However, the additional criteria (applied to break ties when slot requests of the same type overlap), are more ambiguous. In collaboration with several schedule coordinators (namely ANA/Portugal, ANAC/Brazil, BSC/Belgium, CAN/Norway, and, especially, COHOR/France), we have "translated" the additional criteria specified in the WSG into quantifiable objectives properly aligned with their practices. These objectives are the minimization of: maximum displacement (subsequently abbreviated to *maximum*); total displacement (*total*); seat displacement (*seat*); large series displacement (*large-series*), e.g. series of 10 weeks or more; season-long series displacement (*season-long-series*); international flights displacement (*international*); long-haul

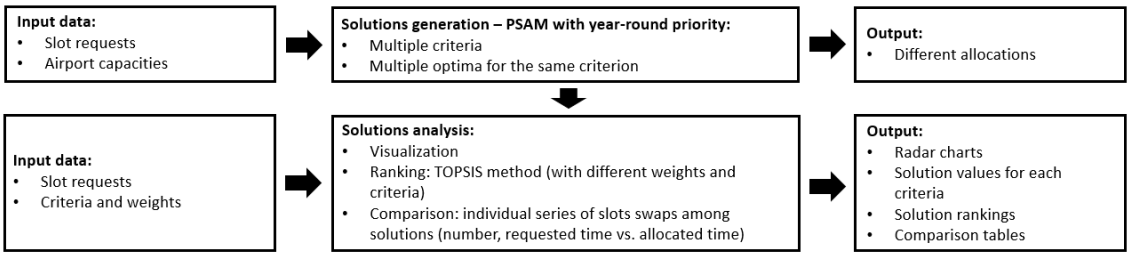
flights displacement (*long-haul*); flights between level-3 airports displacement (*level-3*); and home-carrier flights displacement (*home-carriers*).

The schedule coordinators must consider all or some subset of these objectives in allocating slots. Different objectives, taken separately or in combination, naturally lead to different optimal or efficient slot allocations. Even for the same objective, cases of multiple alternative optimal slot allocations can be frequent. On the other hand, many slots can be optimally or efficiently allocated at the same time for all objectives. The remaining slots – i.e., those which are scheduled differently depending on the objectives at hand – are the ones requiring the greatest attention of coordinators, and are therefore the ones that the decision-support tool we introduce in this paper analyzes in more detail.

3. Decision support tool

The proposed decision-support tool consists of two modules: solution generation and solution analysis. In order to generate the different slot allocation solutions, we use PSAM, enhanced to encompass the different objectives (and the corresponding additional criteria) presented in the previous section, as well as year-round priorities (IATA, 2017, Section 8.3.6). For each objective, a different optimal slot allocation is computed. The input data for this module are the slots requested by airlines and the capacities declared by airports (runway, terminal and apron). The solution analysis module allows computing and visualizing the value of each optimal solution for each criterion (as well as the number of slots displaced – *slots-displaced*), ranking the solutions, and comparing them in terms of slot swaps. The slot requests and the weights assigned to the different criteria are the input data for this module. The outputs are the solution values, radar charts representing these values, solution rankings (considering different weights for the criteria) and comparison figures/tables. In Figure 1, we display a schematic overview of the decision-support tool.

Figure 1 Optimization-based decision support tool overview



4. Airport of Guarulhos

The application of the decision-support tool will be illustrated for the airport of Guarulhos, in Sao Paulo, Brazil. In 2018, this airport handled approximately 300,000 flights and 39 million passengers, being the busiest airport in South America. The examples we provide refer specifically to the change-to-historic slot requests made to ANAC (the schedule coordinator) for the winter season of 2018. As can be seen in Table 1, approximately 50% of the total number of slots requested were of this type – a very high percentage as compared, for instance, with the equivalent figure for the busiest airports in Europe. This could make the optimization of slot allocation difficult, but PSAM was able to perform it in around 30 minutes for each objective.

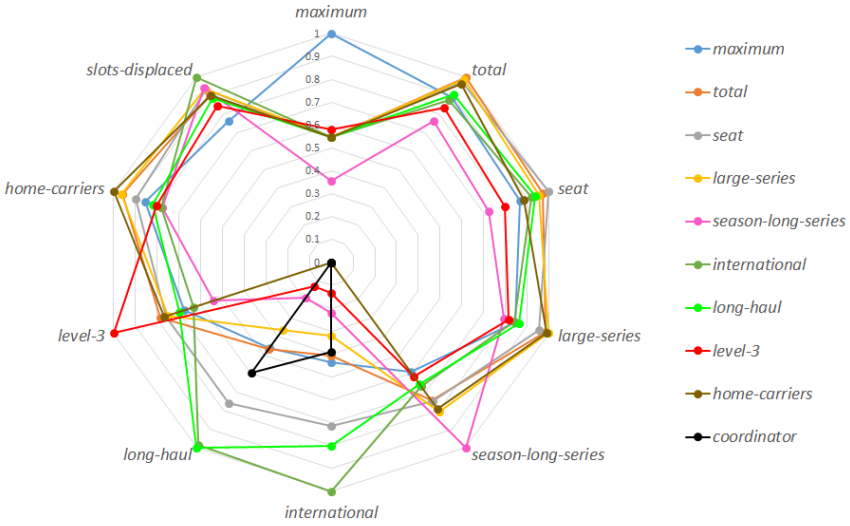
Table 1 Slot request statistics for the winter season of 2018 in the airport of Guarulhos

No. days of the season	154	No. historic slots	21716 (14%)
No. slots	161469	No. change-to-historic slots	80162 (50%)
No. requests	3221	No. new-entrants slots	2354 (1%)
No. series	10398	No. other slots	57230 (35%)

5. Application examples

Some examples of the results the tool can provide to schedule coordinators are shown in this section. The values of the optimal slot allocation solutions computed for the different objectives (first module of the tool) and then analyzed (second module of the tool) can be visualized in a radar chart, as the one displayed in Figure 2. In this figure, the polylines represent the solutions obtained when each objective is optimized, as well as the solution adopted by ANAC (*coordinator*). The positions of their vertices correspond to the values of the solutions considering the different criteria under analysis normalized between 0 (worst) and 1 (best). Through this chart, it is easy to observe the similarity of solutions – for instance, it can be seen that *total* and *large-series* solutions are similar, while *level-3* and *seat* solutions are quite different. Moreover, it can be concluded that the coordinator solution is not efficient ("triangle" in black lines), being outperformed by several other solutions.

Figure 2 Radar chart of optimal slot allocation solutions



To rank the solutions, a well-known multi-criteria method is applied within our decision-support tool: TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution). This method determines scores to solutions based on the weights assigned to the different criteria (reflecting their importance to the coordinator using the tool). In Table 2, the results obtained by applying two different sets of weights are presented: same weights for all criteria; and double weights for *maximum* and *total* in relation to the other criteria. The optimal solutions for the objectives *international*, *long-haul* and *seat* occupy the top-3 positions of the ranking (in the same order) under both sets of weights.

Table 2 TOPSIS scores and ranking for two different sets of weights

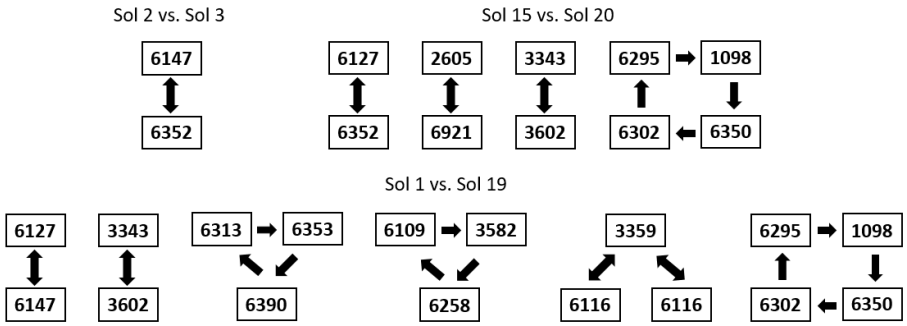
Criteria	Same weight for all criteria		Double weight for *maximum* and *total* criteria	
	TOPSIS score	TOPSIS rank	TOPSIS score	TOPSIS rank
maximum	0.4350	5	0.5171	4
total	0.4559	4	0.4469	5
seat	0.6325	3	0.5821	3
large-series	0.4003	6	0.4019	6
season-long-series	0.3109	7	0.2783	9
international	0.6579	1	0.6087	1
long-haul	0.6459	2	0.5971	2
level-3	0.3093	8	0.3147	7
home-carriers	0.2533	9	0.2789	8

The tool also provides detailed information on the optimal slot allocation solutions for the different objectives and/or for the same objective (i.e., multiple optimal solutions). In particular, it provides information on the slot requests that are accepted, displaced by the same

amount of time or rejected in every solution, as well as on the slot requests that are displaced by a different amount of time in different solutions. In the airport of Guarulhos, comparing the solutions obtained for the different objectives considered, we observed that 72.5% of the slots are allocated to the exact same times in all the solutions. The fraction of slots that require attention from the coordinator is therefore relatively small (27.5%).

To finalize the presentation of the tool, we focus on how it handles multiple optimal solutions for the same objective. To identify such solutions, we run the PSAM during 3 days with the objective *international* (i.e., the objective corresponding to the solution ranked by TOPSIS in the first position). During this run, 23 optimal solutions were found. Comparing these solutions, it was possible to conclude that only 20 series of slots change between solutions (2.6% of the slots). In some cases, only two series of slots are swapped between solutions, as shown in Figure 3. This is the case of the series of slots for flights number 6147 and 6352. But, in one case, 17 series of slots are swapped, and the swapping pattern is quite complex.

Figure 3 Examples of swaps of series of slots



5. Conclusion

In this paper, we introduce a decision-support tool for assisting schedule coordinators in airport slot allocation decisions. It is based on PSAM, an optimization model that fully complies with IATA's World Slot Guidelines (WSG). This model was augmented with objectives corresponding to all the additional criteria for slot allocation specified in the WSG. The tool offers solution generation, evaluation, visualization and ranking capabilities that can be greatly beneficial to coordinators' work. While still undergoing further development, the tool can already be used in practice with fruitful results even at the busiest airports, as demonstrated by its application to the airport of Guarulhos.

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