# A SOCIO-TECHNOLOGICAL APPROACH TO IMPROVE THE PERFORMANCE OF THE AIRCRAFT BOARDING PROCESS

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## ABSTRACT

Airports are critical transport infrastructures supporting different tight interdependent operations that must be properly coordinated to avoid delays on the departures. A sustainable air transport system requires that the strategic planned departures could be preserved at operational time, to avoid downstream overcapacity problems at the airside. In this paper it is introduced some of the perturbations that affects the aircraft turnaround time and the importance to improve the robustness of those operations, which are more sensible to uncertainties generating departure delays. A new boarding MAS algorithm based on a socio-technological system approach is presented, removing some barriers in its deployment.

**Keywords:** security screening, slot assignment, queuing, capacity demand balances

## 1. INTRODUCTION

Air transport system requires the implementation of new processes, procedures and techniques to tackle the growth in air travel demand, which now a days saturates present Air Traffic Management (ATM) resources both at airside and at landside [5,6], resulting in poor KPI's during certain time peak periods.

In the service sector, it is well accepted that resource-saturation usually is the cause of delays that affects drastically different quality indicators. Furthermore, a tight interdependency between a service-chain allows the free propagation of a delay through the different processes provoking idleness and saturation dynamics.

At the airport landside, delays can be generated due to a saturation of airport infrastructure or a poor coordination of the different services that should be provided to the aircraft during the turnaround process.

Turnaround is defined as the period of time the aircraft is on the ramp between an inbound and outbound flight, and different ground- handling operations are performed. Ground handling comprises the activities, operations procedures, equipment requirements, and personnel necessary to prepare an aircraft for the next flight. Many aircraft delays can be attributed to overlong turnarounds due to a lack of planning integration of the different activities and an inefficient use of resources. In addition, the ground tasks are very interdependent. Each operation is a potential source of delays that could be easily propagated to other ground operations and other airport sub-processes [3].

Despite several efforts to improve the robustness of the turnaround processes to avoid the generation and propagation of delays through other aeronautical processes, now a days, turnaround is still considered the weak cornerstone in the airport due to the tight interdependencies between the tasks to be executed in an operational context characterized by uncertainties and decision making tasks fragmented between different stakeholders.

Most relevant stakeholders that participates in the decision making process during turnaround operations are:

- Airport: Manages the required infrastructures to support turnaround tasks. Some decisions, which can drastically affect the turnaround scheduling, is the parking and door assignment. Thus, a remote position can require some extra tasks (ie. transport of passengers to the parking position, stairs, etc) while some others can be avoided (pushback on autonomous positions).
- Airlines: Are the responsible to extend the turnaround time to tackle unpredicted disturbances (ie. a non-shown passenger) and accept or not late baggage.
- Handling Companies: They must coordinate most of ground operations considering the precedence spatio-temporal constraints.

Additionally, all the stakeholders use their own resource management systems and resource optimization systems to satisfy their particular business goals. The different criteria used for each stakeholder may lead to solutions incoherent with the rest of the stakeholder's needs, leading to inefficiencies. In order to fill this gap, the Airport-CDM concept arose [2], aiming to improve the overall efficiency of operations at an airport through collaborative planning and information sharing among stakeholders, with particular focus on the aircraft turn-round and pre-departure sequencing processes.

**Figure 1: Independent Process Oriented Turnaround**

The INTERACTION Project proposes to improve the efficiency of airport processes through the integration of the 4 independent turnaround sub processes (Figure 1) by considering the different interdependencies and providing new processes to mitigate the propagation of disturbances.

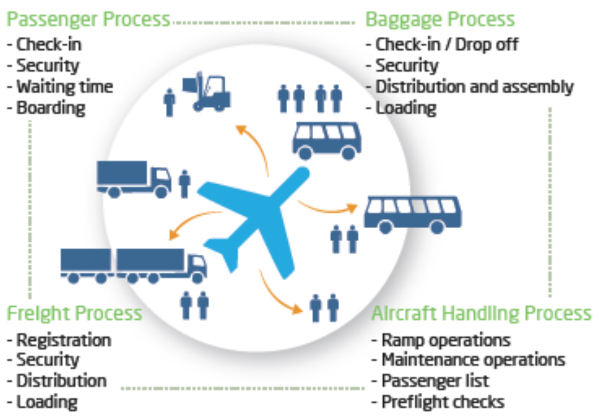

**Figure 2: Interaction : Turnaround as a whole**

In Figure 2 it is represented the new approach developed in INTERACTION project in which a central information system has been implemented to support the proper monitoring of the different tasks and turnaround milestones and enhance a coordinated decision in case of deviations with respect to scheduled actions.

As it can be observed in Figure 3 the reduced space located around the aircraft which is shared between all the ramp handling equipment is a source of tight spatial interdependencies. On the other hand, logical precedence requirements such as passenger disembarking precedence to cleaning and to the embarking process are a source of tight temporal interdependencies. Thus, tight spatio-temporal interdependencies between the turnaround tasks that should be finalized in a short period of time deals with a complex system in which decision making must consider all downstream consequences.

In INTERACTION it has been developed a causal model using Coloured Petri Net (CPN) formalism to analyze all the physical and temporal interdependencies and some control mechanisms to mitigate the propagation of perturbations between turnaround processes that are placed in the critical chain. Among the turnaround operations with a non-deterministic duration time, there are 3 ground tasks that provides a higher level of uncertainty:

- Boarding: The boarding process is very sensible to the boarding sequence and the characteristics of the passenger, providing as average an increment of 7 minutes with respect to scheduled time.
- Bulk Loading: It can impact on an increment of 12 minutes with respect to scheduled time
- PRM arrival: Passenger with Reduced Mobility can impact with an increment of 8 minutes with respect to scheduled time.

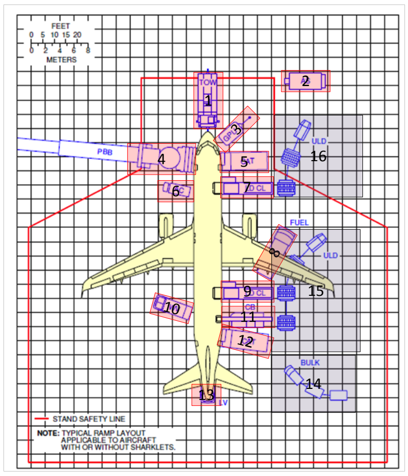

**Figure 3: turnaround ramp handling tasks**

Among these 3 turnaround operations with highest stochastic duration time, only the Boarding process is always in the critical chain. In this paper it is presented a description of the main disturbances that affects the boarding process and a Multi Agent System model that has been implemented in Netlogo to mitigate the effects of disturbances and improve the robustness of the boarding process.

## 2.- THE BOARDING PROCESS

During the boarding process, passengers use to compete in the terminal area to get inside the aircraft through a Boarding Pass control.

Inside the aircraft, the space in the aisle is quite reduced generating flow conflicts and interferences between passengers that can block the boarding flow. The main conflicts, which can affect the boarding speed, are:

- Placing a luggage in the overhead compartment: In case there is room in the overhead compartment this time can be modelled as a stochastic process, however when overhead compartments are nearby saturation (ie. the lasts boarding passengers), the time required to find an overhead compartment with enough room to place the luggage is tightly dependent on the amount of passengers in the aisle.

- Placing a coat in the overhead compartment: Specially, in winter time and old people, to remove the wearing coat in a reduced space and placing the coat in the overhead compartment avoiding to loose the objects (coins, keys, mobile,…) from their pocket, usually impact on the boarding time.
- Latent Aisle capacity: Distance between passengers waiting in the aisle is 2 or 3 time bigger in the embarking that at disembarking. It is easy to see how passengers take profit of any space in the aisle when preparing the disembarking while the door is still closed.
- Taking a seat: The time it takes a passenger to leave the aisle after having arrived at his or her seat's row and having stored the luggage, depends on the seat location in the row and if another passenger is seated in the row and need to leave their seats in order for the current passenger to sit down.

There are several algorithms reported in the literature that try to maximize the boarding speed considering somehow the above-mentioned conflicts, among them, the most relevant are mentioned bellow with some new insights obtained using the MAS model developed :

**Random Boarding**: There is no pre-established sequence of passengers boarding the aircraft. Some authors claims that random boarding provides the best boarding time because passengers are spread through the aircraft seats.

According to simulations results obtained using the MAS model developed and an analysis of passenger interdependencies, one of the main causes of these good boarding time achieved using Random policy is because the passengers with the most carry-on bags try to in the first positions of the boarding queue since they are afraid about lack of room in overhead compartments, while passengers without bags prefer more to spend their time in the commercial area instead of queuing long time before the embarking. In [1] it is shown how the "passengers with the most luggage board first" policy provides good results in terms of the total time for all passengers to board. Furthermore, the sooner it is detected that overhead compartments are saturated the better, since airlines companies can ask earlier passengers to leave the baggage outside the aircraft to be loaded in the bellies providing indirect benefits in the turnaround time.

**Back-to-Front**: Passengers are grouped according to their assigned row and embarking is performed by groups of passengers with rows assigned in a descending order. The most popular implementation is to split passengers in just two groups (passengers from rows 16 to 23 and from1 to 15). Smaller groups could also be implemented but experimental results are worst that the Random policy.

One of the reasons that justify these results is because the amount of aisle conflicts increases considerably when passengers are concentrated in the same area, and lack of interaction between passenger's together with random sequence inside the group leads to situations in which passengers are seated in the sequence C B A (see Figure 4) increasing the "Taking a seat" time which will be additive to the placement of baggage.

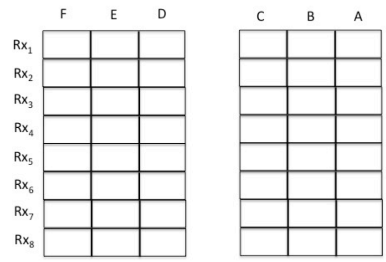


Figure 4: Seat distribution

**Front-to-back**
This policy is quite similar to the previous embarking policy (back-to-front) but groups of passengers seated at the front of the aircraft will embark before than passengers at the back.

According to experimental results, this policy provides the worst embarking times, which is justified because aisle blockages compute multiplicatively (few concurrent aisle blockages) instead of additively ( several blockages takes place in the same time).

**WILMA Algorithm**
Passengers are assigned to 3 groups: passengers with a window seat (group 1), passengers with a middle seat (group 2) and passengers with aisle seat (group 3). Boarding is organized using the same order of the groups.

Experimental results confirm that "Taking a seat" blockages are minimum.

**Reverse Pyramid**
Some authors consider this policy as a combination of back-to-front and Wilma embarking policies, since passengers are sequenced providing priority to windows seats at the back of the aircraft.

The experimental blockages observed provides a good trade-off between "Taking a seat" and "placement of baggage" with a good rate of concurrent blockages.

**Steffen**
For an aircraft with 20 rows and 120 seats, passengers are split in 12 different groups each one with 10 passengers. First passenger is seated in the window of

the last row and the next passengers are seated in the window of two rows ahead of its predecessor. This sequence is repeated for the passengers with a window seat located at the other side of the aisle. Once odd windows are occupied the next passengers are seated in even windows repeating the same procedure. Once all windows are full, the next passengers are seated according to previous steps but in the middle seat, and once all middle seats are full passengers are seated at the aisle according to the same sequence used in window seats [7].

Assuming that baggage is randomly distributed through passengers, blockages due to aisle latent capacity and "taking a seat" time are minimum while the concurrency of blockage due to placement of baggage is maximized. In Figure 5 it is represented the aisle blockage results applying Steffen boarding algorithm with a row-to-row deterministic time of 2 seconds and 7 seconds for taking a seat and placing 1 baggage with a configuration of 7 rows. In the Y axis B is used for aisle Blockage and F for aisle Flow. As it can be observed, the 7 seat windows (F) are first assigned and then the other seat windows at the other side of the aisle (A) are assigned alternatively.

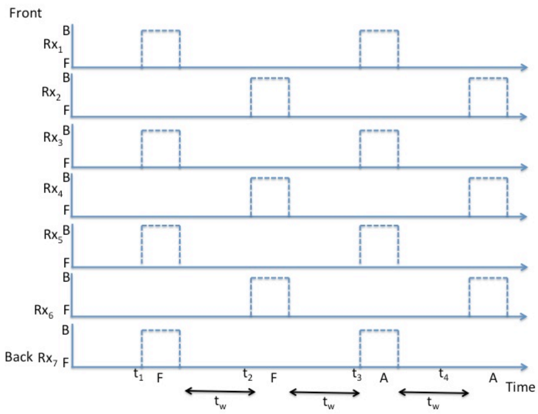


**Figure 5: Aisle blockage concurrency**

Aisle blockages at the different rows takes place at the same time which allows longer time periods in which the aisle is free of blockages improving the averge speed boarding flow. These excellent results can only be obtained if deterministic times are considered for the "row-to-row", "time to seat" and "placement of hand baggage". However, saturation of overhead compartments impact negatively on boarding performance, with more sensitivity effects in the front seats. In Figure 6 it is shown how extra time to store a luggage affects the aisle blockage times and in consequence the accessibility of passengers to reach their seats. The time to store a luggage is computed according to the next equation described in [1]

$$T_{sl} = \left(\frac{n_{bin} + n_p}{n_p}\right) \times n_p \times t_{row-to-row}$$

In which

- $T_{sl}$ : The estimated time to store a luggage in the overhead compartment.
- $n_{bin}$: The number of luggage already in the overhead compartment
- $n_p$ : The number of luggage the passenger must store
- $t_{row-to-row}$ : Time to move from one row to the next

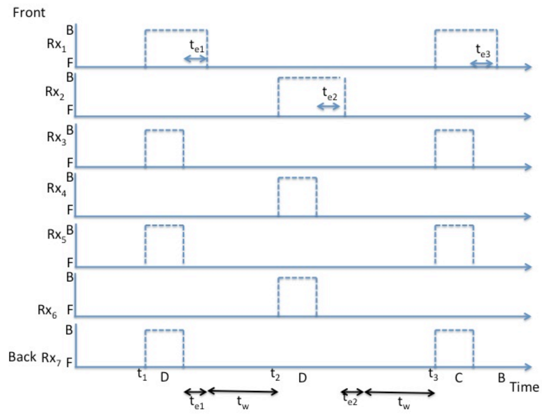


**Figure 6: Increment of blockage time due to extra time for storing luggage**

## 3.- SOCIO TECHNOLOGICAL BOARDING APPROACH

Despite the excellent robust results that can be achieved using Steffen algorithm if overhead saturation problems are not considered, it is recognized that the acceptability of the algorithm is really low for passengers since it requires to split a group (ie. family with kids should embark at different times) and also generates pre-embarking problems since sometimes the right passenger is not located in the gate at the time required by the Steffen algorithm.

A socio technical approach to the boarding problem has been considered in which the developed MAS model considers not only the control variables but also the influence variables. Thus, agents can interact between them in a local context to minimize conflicts while maximizing benefits. In INTERACTION it has been assumed the use of reward mechanisms (such as extra miles, a free drink consumption, etc) to enhance the cooperation between passengers.

Cooperation between passengers to achieve a short boarding can be represented by means of influence variables in which the passengers located at a neighbourhood of 2 -3 ahead or 2 – 3 back in the lane (preferably at finger) can be influenced for a local re-sequencing satisfying window – middle – aisle if they are seated in the same row.

A MAS model has been implemented in Netlogo in which the main influence variable to achieve a re-sequencing in the lane considers the next 3 factors:

- Age: Young people are more aware of airline reward mechanisms, willing to obtain always extra miles or any other advantage provided by the airline.
- Location: Passengers in a window seat assigned will be much more pro-active to check with the neighbourhoods passengers if they have a middle or aisle seat in order to swap in case are in the same row.
- Willingness: The main barrier for the acceptability of a swap are: the language problems, reduced mobility passenger problems, and fear about overhead compartment saturation.

Different weights are assigned to the 3 influence factors to succeed with a sequence swapping meanwhile passengers are still waiting to reach the aircraft door (pre-embarking area or finger). As extreme scenarios for validation purposes it is considered that in a group of 6 passengers with 3 or more young people, the re-sequencing is guaranteed. In case there are not PMR's with only 2 young people it is also guaranteed. On the other hand, it is considered that a group of 6 elderly tourists with 2-hand baggage per passenger at the latest stages of embarking wouldn't accept easily a swapping due to fear about lack of room in the overhead compartment to store their luggage.

In order to remove some barriers of the Steffen algorithm in which group of people (ie. families, friends, etc) should embark at different times, it has been developed a model in which passengers embark according to a pre-established sequence of rows which has been formulated considering the occupancy factor and the latent aisle capacity. Thus, for an aircraft with 100% occupancy with 20 rows the sequence of rows proposed is:

20 15 10 5 19 14 9 4 18 13 8 3 17 12 7 2 16 11 6 1

This sequence somehow tries to combine the benefits of back-to-front with Steffen and WILMA algorithms. Thus, first row to embark is the row at the back (ie row 20) in which the 6 passengers are re-sequenced (as :

F A E B D C

The next row is located 5 rows ahead (ie. row 15) since the aisle space between row 15 and row 20 is used by the passengers with seat at row 20 meanwhile they are storing their luggage in the overhead compartments. Note that the storage of the baggage is performed by the passengers at the same time, thus the aisle is blocked by the 6 passengers of the row at the same time and it doesn't affects the movement of passengers in the aisle to reach row 15. Furthermore, the local re-sequence achieved through the use of reward mechanisms minimizes the time-to-seat in the row.

In Figure 7 it is represented the simulation of the sequence at different time intervals in which the blue colour represents the aisle of the aircraft and the brown colour the seats. Thus, Figure 7 (a) illustrates the seat occupied by the first 4 rows of the sequence (ie. 20, 25 10 and 5). In part b) it is visualized the boarding until row 4, in part c) it is visualized the boarding until row 3 and in part d) until row 2. As it can be observed in part c) the 6 passengers at the top part of the aisle are moving without any aisle blockage until row 17.

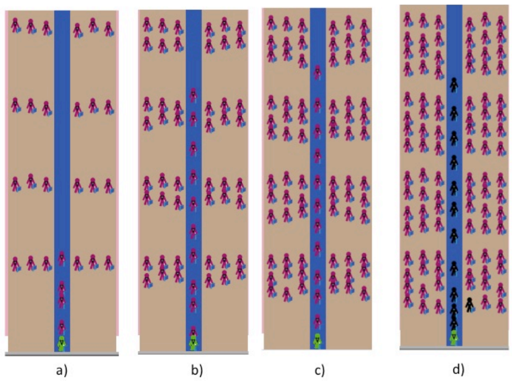


**Figure 7: Boarding by rows**

Using the proposed sequence, the boarding speed flow is interrupted only 4 times when passengers of rows 5, 4 3 and 2 stores their bags in the overhead compartments. In fact, the boarding flow it is interrupted according to:

20 15 10 5
19 14 9 4
18 13 8 3
17 12 7 2
16 11 6 1

In the top side of Figure 8 it is represented the amount of people generating a blockage in the aisle. As it can be observed, the passenger of seat F in each row blocks the aisle during the $T_{sl}$ time which is used also by the other passengers of the same row to store their bags in the overhead compartment. Time between 4 consecutive blockage correspond to the time required by passengers to reach their row. At the bottom part of the same figure it is represented the amount of passengers that are blocked in the aisle. Some of the reported blockages are due to the speed differences of passengers walking thorough the aisle and the latent capacity generated by trolleys.

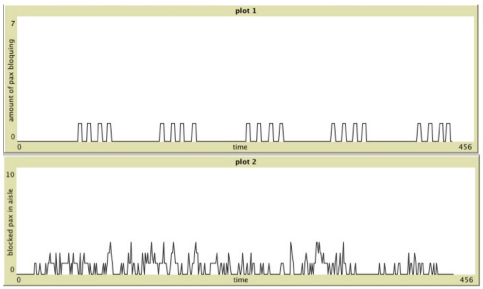

Figure 8: Boarding results using proposed sequence

## 4.- SIMULATION RESULTS

The proposed algorithm tries to minimize both the severity and the amount of aisle blockages, by combining the benefits that can be obtained by the Back-to-Front boarding algorithm, the Steffen algorithm and WILMA algorithm.

In Table 1 it is summarized the boarding times obtained with similar passenger profiles and amount of hand baggage to compare the benefits of the proposed embarking sequences with respect to Steffen sequence [4]. As it can be observed, Steffen provides better boarding times in those flights in which hand baggage is minimum (ie. business flights). A possible reason that justify this small difference is that the first 2 passengers in the row (ie. seats A and F) shares the same aisle area to reach their seats while this situation doesn't appears in the Steffen algorithm.

With a random low amount of well distributed hand baggage both algorithms provides similar boarding times, however the proposed algorithm is much robust and provides better boarding times when the amount of hand baggage is nearby saturation.

| New Algorithm | | Steffen Algorithm | |
|---|---|---|---|
| Boarding Time | Amount of Hand Baggage | Boarding Time | Amount of Hand Baggage |
| 6' 50'' | 0 | 6' 37 '' | 0 |
| 7' 3'' | 54 | 7' 3'' | 57 |
| 7' 13'' | 98 | 7' 21'' | 102 |
| 7' 24'' | 95* | 9' 29'' | 96* |

Table 1: Boarding time simulation results

Last experiment reported in the table (last row marked with *) consists of an scenario in which passengers at the front of the aircraft have at least 1 hand luggage (maximum 2) that must be placed in the overhead compartment. As it can be observed, Steffen algorithm performance is affected since the aisle is blocked at consecutive times, while the new algorithm is much more robust because passengers of the same row stores the baggage at the same time (ie. task performed in parallel).

In Figure 9 it is represented the amount of passenger blocking the aisle (upper side) and the amount of passengers blocked (lower side) in the scenario requiring 9' 29'' to complete the boarding.

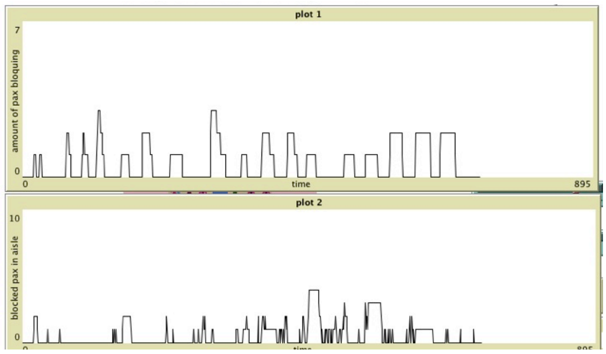

Figure 9: Steffen Boarding results with passengers with 1 or 2 baggage at the front

## 4.- CONCLUSSIONS

A new boarding algorithm has been designed to improve the robustness of present algorithms which usually do not consider the disturbances of overhead compartment and its saturation.
The implementation of reward mechanisms can be easily designed together with the airlines to enhance passengers to facilitate a local re-sequence while waiting at finger. The results obtained at simulation opens new opportunities to airlines to exploit the seat assignment considering passenger willingness to benefit from rewards.

## ACKNOWLEDGMENTS
This work is partially funded by FP7 INTERACTION project, and MINECO project "Fire Guided Unmanned Aircrafts and Resources Distribution (TIN2014-56919-C3-1-R).

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