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# Airplane boarding optimization using Multi-Agent systems

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# Abstract

Airplanes turnovers are one of the main worries for airline companies because can cost to airlines companies thousands of Euros as well can impact in customer satisfaction due to delays that may occur. Airplane boarding is the most critical event of airplanes turnovers and it is necessary to have some boarding strategy to reduce the time of boarding. Various strategies are used by companies such as Random boarding, boarding Back-to-Front, or boarding by blocks. However, there are other complex strategies proposed by various authors that are very efficient, but only in theory and very difficult to implement in real situations. In this work, we will simulate the most used strategies used by companies using a multi-agent system (NetLogo) with the objective to analyze and clarify the best boarding strategy as well as compare to one of many ideal boarding strategies(Wilma(windows-middle-aisle)). It was defined a simulation scenario for a narrow body airplane with one entrance with 24 rows and each 6 seats for row. After the tests, we see that Random boarding except for the ideal strategy is the efficient way of boarding passengers to the airplanes.

# 1 Introduction

The airplane has become an integral part of our everyday transport. According to FAA there are over 20000 commercial flights per day in the US [4]

To maintain competitiveness between Airline companies, makes necessary that any airline companies need to keep the airplanes running as long as possible. To keep aircraft running as long as possible, it's necessary to find good methods to reduce the time in ground. The boarding is an inevitable process set that can influence the total time on the ground. Also, the satisfaction of passengers is closely associated with the boarding process, which in return, influences the business strategy of airline companies.[3]

Various boarding methods are used by airline companies to board passengers such as rear-to-front, WilMA (Windows, Middle, Aisle), random and blocks, etc... [7] In this work we will study some methods to boarding passengers, by replying them in multi-agent systems and analyze each of them to search for the best way to board an airplane, that it that take the minor time.

Intelligent agents are systems capable to understand and modify their surrounding environment, automatically, to find the best results. An agent is anything that can be views its environment through sensors and action upon the environment through actuators. (Figure 1). For example, a human is an agent that has sensors such as eyes or ears and actuators such as hands or legs. An agent can be replied by software that receives keystrokes, and data as sensory inputs and acts on the environment by displaying on the screen or writing data to files, for example. Mathematically speaking, we say that an agent behavior is described by the agent function that maps any given precept sequence to an action. [8]

The intelligent agents are commonly used in resolution and analysis of optimization problems through multi-agent systems.The literature focused on resolving optimization problems, such as plane boarding use multi-agent systems.

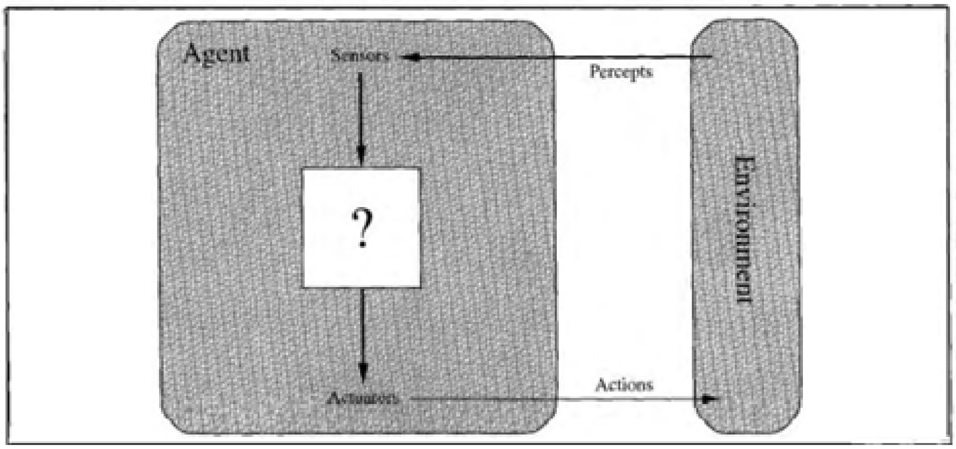


Figure 1: Agent and Environment relationship based on [8]

In [1] the authors study the boarding problem via multi-agent based simulation, often referred to as ABS. With ABS the authors introduce heterogeneous population, that is, define passengers with a set of various attributes such as, create disturbances, to offer a richer model of simulation. Various boarding methods were studied, where some disturbances were inserted in the study such as passenger compliance, passengers' groups, and transit passengers. The strategies to board used in this paper the airplane in blocks of similar size were divided, so that passengers assigned to the same block can board the plane at the same time. The order with which a block of passengers can board the plane can be ascending or descending according to their block number. Other strategy used was to divide the plane in 6 blocks that starts at the end of the plane and then 3 blocks are skipped and when are no more blocks, ordering restarts again from the back of the plane. Another strategy is to consider the rows in blocks, that can be boarding mixed, as well as consider divide the 2 aisles of one row into 2 half-blocks. Another strategy used was to perform boarding from windows to corridor, possibly alternated. Another strategy used is to call every passenger by their seat number individually. Finally, the last strategy used blocks, that will be further refined in sub-blocks using the seats of same columns and these sub-blocks are order via pyramid structure. Is important to note that more strategies were used that are sub-variants of the explained above. After tested the various strategies the authors conclude that the strategies to board the passengers by boarding by seat number and the strategy by pyramid but was referred that these boarding procedures are not very passenger-friendly and costly to implement.

In [5] the authors experiment six boarding methods using agent-based computational model and suggested a new method which by the authors reduced the boarding time significantly. The boarding methods compared were founded in the literature and focused on the following methods: Random, that all the passengers board without order; Wilma(windows-middle-aisle), that all passengers seated at the windows are boarding in the first group, followed by the middle seats group and the aisle seats group; Back-to-front, that is boarding from the back to the front with the passengers from the window boarding at first; Blocks, that boarding is in four-row blocks were the back four rows are the first boarding group, followed by the front block and finishing with the center four rows block; Steffen that is a method proposed by Steffen were adjacent passengers in line are sitting two rows apart from each other in corresponding seats (e.g. 12A, 10A, 8A, 6A, etc.); And Kautzka, the model proposed by the authors that is a combination of 3 methods: Wilma and Back-front and parallel luggage stowing. To evaluate the different methods, the Netlogo tool was used, where different variables to improve the simulation were used, such as passengers with luggage, if a passage is delayed, among others. The authors conclude that the method proposed by Steffen and the model proposed by them in a theoretical way are very effective. These authors also mention that these arrangements of passengers do not seem to be realistic because passengers are not used to it. With these two papers analyzed, we see that various efficient models were suggested but not applicable in a real situation.

# 2 The challenges behind airplane boarding

An airline company generally only makes money when it's flying. The time lost in ground either boarding or deboarding passengers, that is the turnaround. The turnaround time is a traditional metric used to measure the efficiency of airline operations and is the very basis of the company sustainability in terms of generated costs. Turnaround it is defined as the period between the airplane's arrival and departure from an airport.[6] In [10] authors estimated that the per minute cost for each airplane is between $30 and $77 during the turnover period. So, it is valuable time and money that airline companies always try to reduce.

Various strategies are used by airline companies to board people as fast as possible. The most used strategies are the Back-to-Front strategy where passengers seated in the last rows enter first, the random strategy where the passengers enter the plane without any order and the block strategy where passengers are divided into blocks and the boarding procedure is made one block by time.[2] These strategies, in a theory point of view, are not very efficient as shown in various papers, but there have emerged new strategies for boarding as seen before, but these strategies are very hard to implement in real context, mainly because the time and cost to organize the passengers at the result does not compensate the time that might be saved. In this work we focus on analyzing the main strategies (Random, Back-to-Front, and by Block) that can be applied and used by airline companies as well as implement a more efficient method (Window-Middle-Aisle), in theory, to have a comparison strategy to well analyze the most used strategies. [9]

We focused on implementing a simulation system for the vast majority type of airplanes currently in operation that are the narrow body airplanes. These airplanes can take around 250 passengers and mainly do short and medium haul flights. It was also considered one boarding gate, because a lot of airports that are used by these airplanes have only one boarding gate attached to the aircraft.

# 3 Strategies to resolve the problem

To achieve the objective of this work, we will use the NetLogo tool. The NetLogo is a Multi-Agent programmable model environment and can be used to create and program simulation models that can be very useful for analyzing efficiency problems such as ours. This tool has a counter that names "tick" and we consider that "tick" is a unit of time.

Like our work is to simulate passengers boarding an aircraft it is necessary to refer some features. In this simulation we use an example of a narrow-body aircraft like Boeing B737 or Airbus A320. This aircraft only has one entrance, that is in the front, to all passengers enter. There are 24 rows of seats and each row of seats has 3 seats on the left and 3 seats on the right with the aisle on the middle. As we can see in Figure 2

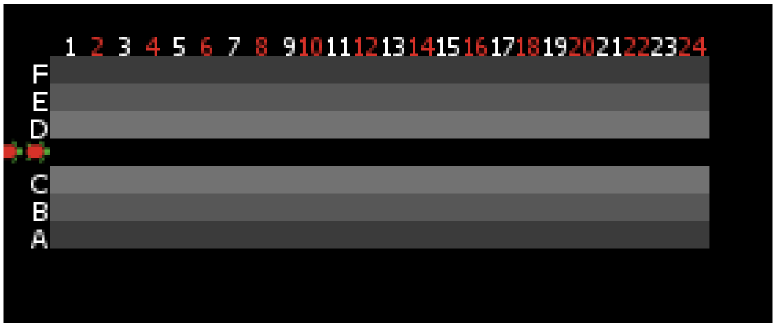


Figure 2: Plane Simulation

To make the simulation more real, each passenger will take 2 or 3 units of time to sit in their seat if the row that he will seat is not already occupied with other passenger. If the row that the passenger will seat is already with any other passenger seat, it will be added 2 more units of time to their sitting time. For example, if a passenger have a window seat on the row number 1 on left side of the plane and if the aisle and the middle seats are not occupied we will take 2 or 3 units of time, but if the aisle or middle seat has already someone it will be added 2 units of time to their sitting time.If the aisle and middle seats are already occupied, it will be added 4 units of time to their sitting time. The sitting time variable applied to any passenger have the objective to simulate the time that passenger will be occupying the aisle, fitting their luggage in the overhead bins and sitting.

To better understand the behavior of the passengers it will be assigned colors to their representation, based on their seat row (Figure 3):

- PINK : Rows 1-6 - Block 1
- YELLOW: Rows 7-12 - Block 2
- BLUE: Rows 13-18 - Block 3
- RED: Rows 19-24 - Block 4

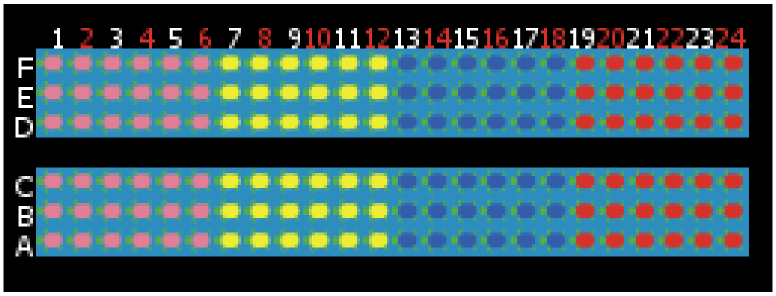


Figure 3: Passengers Blocks

The strategies that we will discuss in this work will be:

- Random Entrance

  All the passengers enter the airplane without any entrance organization.

- Sequential Entrance

  The passengers enter by blocks from the end of the plane to the beginning (Block 4 $\rightarrow Block3 \rightarrow Block2 \rightarrow Block1$).

- Alternated entrance

  The passengers enter by blocks but alternated (Block 4 $\rightarrow Block2 \rightarrow Block3 \rightarrow Block1$).

- Window-Middle-Aisle Entrance

  The passengers enter by blocks from the end of the plane to the beginning (Block 4 $\rightarrow Block3 \rightarrow Block2 \rightarrow Block1$).

# 4 Results

To test the models, we defined in the previous step, it is necessary to run each strategy multiple times. To achieve this, we used "Behavior Space" - an integrated software tool in NetLogo that allows us to perform experiments with models, running each multiple times and recording the results of each run.

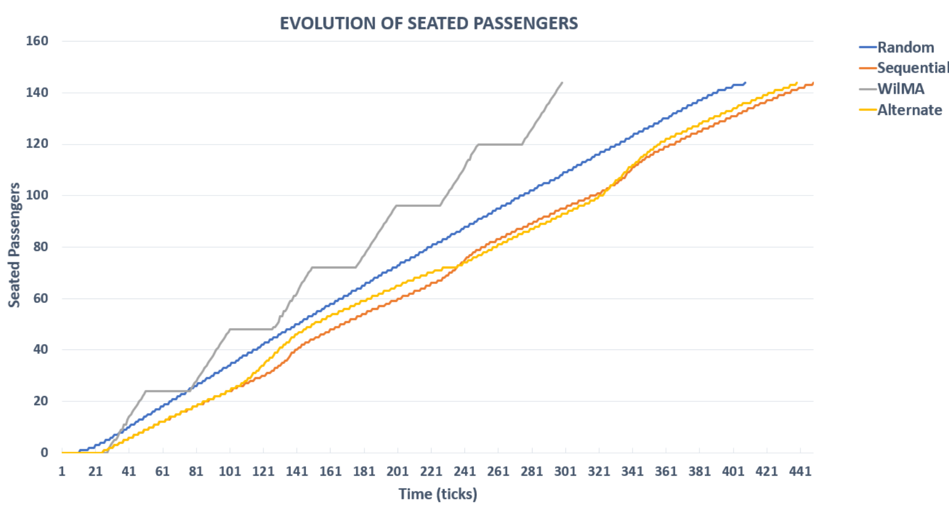


Figure 4: Evolution of Seated Passengers

Each strategy was performed 601 times, with their results recorded. We felt this was a representative number of runs, allowing particularly fast or slow variations of random passenger allocation to be averaged out, while also not taking very long to compute all the runs.

After recording the runs, the median of the number of passengers seated at each tick was calculated for each of the strategies.

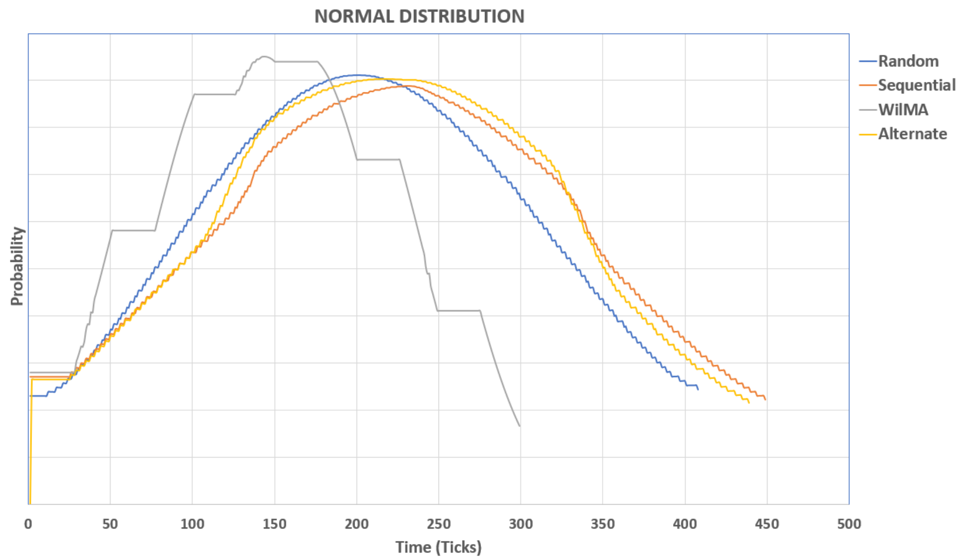


Figure 5: Probability of Seated Passengers

With the results of the runs performed (Figures 4 and 5), we can now make some comparisons between the strategies modeled:

- Sequential Entrance

  Although this strategy seems, at first glance, a good strategy by ensuring that the passengers are seated from back to front, we can see by the simulation results that it is, in fact, one of the slowest strategies. This method took, on average, 450 time units (ticks) to seat all the passengers.

- Alternate Entrance

  This strategy is on par with the Sequential Entrance, with an average of 440 time units (ticks) to seat all passengers.

- Window-Middle-Aisle Entrance (WilMA)

  This is by far the fastest strategy, taking only an average of 300 time units (ticks) to properly sit all passengers. Although we can see by the graph in figure 4 that there are larges gaps of time where no one is sitting (for example from tick 50 to 70), it is followed by a period where passengers quickly get to their seats. This is because this strategy is split between a preparation and a sitting phase, where each row of passengers are walking to their seats (preparation), followed by a quick sitting phase where the entire row seats almost simultaneously.

- Random Entrance

  Almost counter-intuitively, this is the second-fastest strategy of those tested, with an average of 409 time units (ticks) to seat every passenger.

We believe the Random Entrance strategy has a better performance than both the Alternate and Sequential Entrances because, as the passengers and distributed randomly, it allows for more parallelism in sitting – passengers are more likely to reach their seat at the same time, cutting down on time waiting in line – while this is rarer with the Alternate and Sequential strategies, as there are a fewer number of rows "ready to sit" (only one Block is "ready to sit" at any given time).

# 5 Conclusions

After analyzing some work done by other authors, we can see that airplane boarding strategies it is an area that is being studied a lot and there are very interesting and efficient strategies, but in reality that not can be applied because of the time and cost that is necessary to organize the people to enter the airplanes in the right order. Analyzing the experiments that were made we conclude that the various boarding strategies used by airline companies does not differ a lot from each other however we can conclude that the Random boarding procedure is more efficient, because it introduces some aleatory to the boarding allowing for example 3 or more passengers seating in the same time, in different rows. Also, the multi-system agents used in this work, recurring to the tool NetLogo, can be very useful to simulate and analyze efficient strategies that can be applied to many other industries and problems.

# References


[1] Jan Audenaert, Katja Verbeeck, and Greet Vanden Berghe. "Multi-agent based simulation for boarding". In: *The 21st Belgian-Netherlands Conference on Artificial Intelligence*. 2009, pp. 3–10.

[2] Massoud Bazargan. "A linear programming approach for aircraft boarding strategy". In: *European Journal of Operational Research* 183.1 (2007), pp. 394–411.

[3] R Bidanda et al. "A review of optimization models for boarding a commercial airplane". In: *Proccedings of 24th International Conference on Production Research. Poznan, Poland.* 2017, pp. 1–6.

[4] *BTS updates national transportation statistics with sales price of transportation fuels, condition of U.S. Highway Bridges, Vehicle Miles traveled, U.S. air carrier delays amp; Cancellations, and other historical tables.* URL: `https://www.bts.gov/` (visited on 03/30/2022).

[5] Richard Cimler et al. "Agent-based model for comparison of aircraft boarding methods". In: *Proceedings of 30th International Conference Mathematical Methods in Economics Agent-Based*. 2012, pp. 73–78.

[6] Camelia Delcea, Liviu-Adrian Cotfas, and Ramona Paun. "Agent-based evaluation of the airplane boarding strategies' efficiency and sustainability". In: *Sustainability* 10.6 (2018), p. 1879.

[7] *How Different Airlines Board Their Passengers.* URL: `https://lifehacker.com/how-different-airlines-board-their-passengers-1794474413` (visited on 03/30/2022).

[8] P Russel Norvig and S Artificial Intelligence. *A modern approach.* Prentice Hall Upper Saddle River, NJ, USA: 2002.

[9] David C Nyquist and Kathleen L McFadden. "A study of the airline boarding problem". In: *Journal of Air Transport Management* 14.4 (2008), pp. 197–204.

[10] Albert Steiner and Michel Philipp. “Speeding up the airplane boarding process by using pre-boarding areas”. In: *9th Swiss Transport Research Conference, Ascona, 9-11 September 2009*. 2009.