Agent-based model for comparison of aircraft boarding methods

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Abstract. Airline companies need effective boarding methods. Steffen and Hotchkiss compared five boarding methods using real simulation, i.e. experimenting with passengers-volunteers and the realistic model of aircraft. They focused on methods that require arrangement of passengers at the gate. We explored the same boarding methods using agent-based computational model and we have suggested a new method which reduced the boarding time significantly. The influence of the percentage of late or unarranged passengers on the total effectiveness of the boarding process was discussed as well. Our model enables experimenting with various scenarios and parameters' settings such as the number of passengers, the ratio of passengers carrying luggage, the size of the plane etc.

Keywords: agent-based model, aircraft boarding, NetLogo, simulation

JEL Classification: L93, C63
AMS Classification: 90B06, 68M20

1 Introduction

Airports are designed to serve millions of passengers per year. The continuity and accuracy of arrivals and departures is influenced by numerous factors. The efficient boarding procedure is one of them. Agent-based simulation is a useful tool for modelling and exploring dynamic system with interacting individuals. We decided to apply agent-based modelling and simulation to test five boarding methods from [4] together with several new methods we have designed.

The organization of the rest of the paper is as follows. The aircraft boarding methods are analyzed in chapter 2, the NetLogo agent-based model is presented in chapter 3, the experiments are described in chapter 4 and the achieved results are summarized in chapter 5.

2 Aircraft Boarding Methods

The airport boarding is a queuing problem: passengers enter the aircraft one by one, look for their seats, stow their luggage to the box above the seats and sit down. Most airlines use *assigned seating*, i.e. passengers cannot change seat numbers that are printed on their boarding tickets The queue of the passengers in front of the aircraft is not organized (except the preference of the first class, mothers with children, or elderly). Numerous obstructions appear during the boarding process when passengers with the window seats ask passengers from the middle and the aisle seats to get up or multiple passengers put their baggage to the same box etc. These interferences result in delays. The problem of the boarding optimization was analyzed e.g. by Lawson who focused on *unassigned seating* and suggested to use smart swarm concept and ant-based algorithms [2].

Other approaches are based *on arranging passengers* before entering the aircraft. These methods were explored by Steffen and Hotchkiss whose article [4] inspired us. Steffen and Hotchkiss simulated the boarding process with 72 passengers-volunteers and the airplane with 12 rows of six seats and a single central aisle. The objective of optimization was to decrease the number of obstructions, i.e. reduce collision of passengers at the aisle and eliminate the waiting time.

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We focused on 6 methods:

- *Random* – all passengers are boarding together, without specific order. This method corresponds to the traditional boarding process.
- *Wilma* (windows – middle – aisle) – all passengers seated at the windows are boarding in the first group, followed by the middle seats group and the aisle seats group. Inside the group passengers are ordered randomly, therefore there are no seat interferences (situations when aisle or middle seat is occupied before than the window seat), but many aisle interferences.
- *Back-front* – boarding from the back to the front of the aircraft. Passengers seated at the windows are boarding first, followed by the middle and the aisle seats. This method eliminates seat interferences as well as some aisle interferences.
- *Blocks* – boarding in four-row blocks. The back four rows are the first boarding group, followed by the front block and finishing with the center four rows block. The order of passengers in the block is random. Generally, the size of blocks is optional. The optimal number of blocks depends on the length of the aircraft. The number of rows in the block relates the number of seat interferences and aisle obstructions.
- *Steffen* – adjacent passengers in line are sitting two rows apart from each other in corresponding seats (e.g. 12A, 10A, 8A, 6A, etc.). This method attempts to eliminates seat interferences and, as much as possible, aisle interferences while allowing multiple passengers to stow their luggage simultaneously (see Fig. 1).
- *Kautzka 3* – our combination of three principles: *Wilma* and *Back-front* and parallel luggage stowing (see Fig. 1). The method is designed to eliminate both seat and aisle interferences. Our method is also trying to avoid splitting pairs of passengers sitting next to each other – families or colleagues who travel together. More detailed information and our other innovated methods are described in [1].

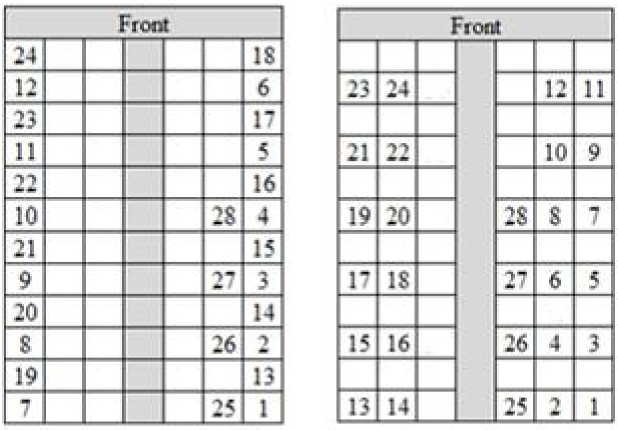

Figure 1: *Steffen* (left) and *Kautzka 3* (right) boarding method

The authors of the *Steffen* method expected that this is the fastest boarding method for airplanes with one entrance and one aisle. Although they did not consider seat interferences, their real simulation results confirmed their expectation. The boarding times were approximately 3.5 minutes for *Steffen* method, over 4 minutes for *Wilma* and *Random*, 6 minutes for *Back-front* and nearly 7 minutes for *Blocks* [4].

Steffen and Hotchkiss could not repeat the real simulation several times and they used only a single setting of parameters (i.e. total number of passengers, number of passengers with/without bags and/or roll-abroad carry-ons). The main problem is that passengers were volunteers and hired actors. Stress, fatigue and other factors does not affect passengers' behavior in the same way as real passengers at airports. Steffen and Hotchkiss' experimental result surely differs from reality in absolute values of boarding times, but the proportion between boarding methods is probably the same also for other settings of parameters.

The boarding methods could be compared in relation to the length of the plane, too. The more rows of seats, the longer boarding process is and the more significant impact of the proper boarding method. In case of the *Steffen* method the total time grows linearly. The *Wilma* method and the *Random* method are less efficient in longer planes because of the unequal distribution of passengers stowing luggage in parallel.

Our objective was to verify the ratios of boarding times from [4]. Moreover we focused on testing the following hypotheses: (a) *Random* boarding is not significantly slower than *Wilma* method, (b) *Blocks* boarding is slower than *Wilma*, *Random* and *Steffen* methods. Here we expected the impact of different usage of the aisle when stowing baggage. *Wilma*, *Random* and *Steffen* methods distribute passengers uniformly along the plane, while in *Blocks* method passengers from the same group obstruct each other.

3 Model in NetLogo

A model is a schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further study of its characteristics. Our agent-based boarding model is built to enable comparing different boarding methods, especially the methods based on specific arrangement of passengers when entering the aircraft. The key element of the agent-based model is an *agent*, autonomous entity with its behavior and properties that operates in the environment. Here the movable *passenger-agents* correspond to passengers, while the plane is represented by *luggage-agents* and the environment. The objective of the agent is to move though the plane to the assigned seat. The sharable description of the model according the standard Overview-Design-Details protocol [3] is presented in [1]. The model was implemented in NetLogo 5.0, a programmable modeling environment well suited for modeling complex systems developing over time [5]. The interface allows modification of parameters of the model and performing experiments (Fig. 2).

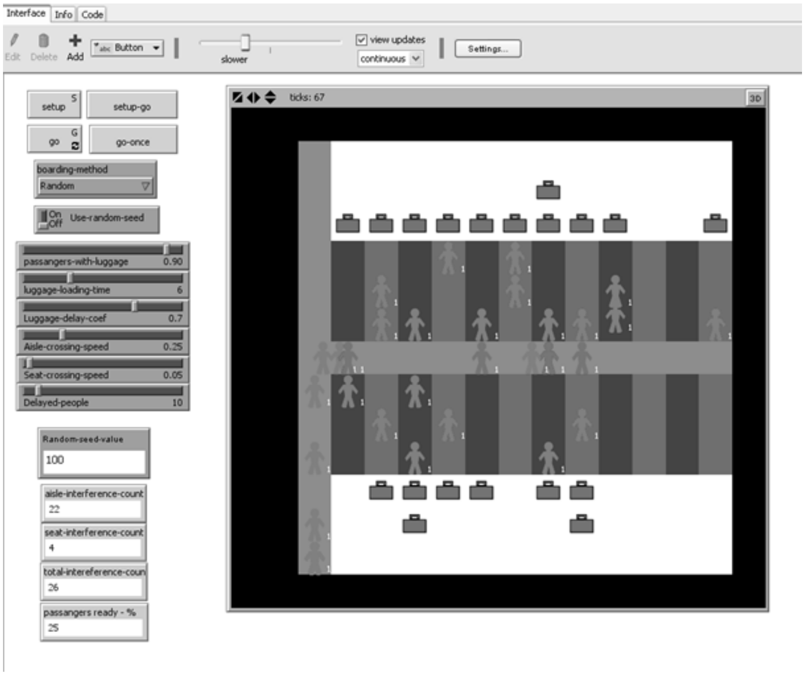

Figure 2: Model interface

Basic assumptions of the model are the same as Steffens' and Hotchkiss' in [4]:

- The plane is fully occupied.
- Each passenger-agent moves independently (the parent-child pairs are not taken into account).
- The proportion of passengers with luggage is optional.
- All passenger-agents with luggage require the same luggage space.
- Two back-to-back passengers can stow the luggage in parallel (the time depends on the value of the luggage-delay parameter setting).

General parameters of the model are:

- *Boarding method* – selection list with 6 possible methods,
- *Use-random-seed* and *Random-seed-value* – switch and slider used for optional repeated runs of simulation the with the same setting of the random number generator,
- *Passengers-with-luggage* – slider for setting the probability of having luggage (for each passenger-agent),
- *Delayed-people* – slider for setting the probability of being late (for each passenger-agent),
- *Luggage-loading-time* – slider for setting initial number of *ticks* necessary for stowing the luggage,
- *Luggage-delay-coef* – slider for setting the increase of waiting time for interferencing passenger-agent,
- *Aisle-crossing-speed* – slider for setting the speed of passenger-agent passing other passenger-agent in the aisle,
- *Seat-crossing-speed* – slider for setting the speed of passenger-agent passing other sitting passenger-agent.

Passenger-agents have got following parameters:

- *Row number*
- *Seat number*
- *Sitting* – true/false value that indicates whether the passenger-agent is already sitting
- *Moving* – true/false value that indicates whether the passenger-agent can move at the moment
- *Waiting* – the number of *ticks* the passenger-agent waits at the same place
- *Luggage* – true/false value that indicates whether the passenger-agent has got a piece of luggage
- *Luggage-time* – the number of *ticks* necessary for stowing the luggage
- *Turn* – the ordering number

The NetLogo environment is the grid of patches. The movement of agent is expressed as modification of [x,y]-coordinate in the grid. In the model the passenger-agent moves zero or one patch per tick of the model clock. The agent tests the patch ahead before making the movement and he cannot access the occupied patch (except passing other stowing or sitting passenger-agent, when these options are allowed).

Four types of interferences of passenger-agents are possible:

- The passenger-agent waits because the other passenger-agent blocks the way.
- The passenger-agent waits because the other passenger-agent puts the luggage to the shared luggage box.
- The passenger-agent has to pass the other passenger-agent stowing luggage.
- The passenger-agent has to pass already sitting passenger-agents.

The run of the simulation stops when all passenger-agents are sitting at their seats. The observed value is the number of *ticks* of the internal clock before the model stops. Implementation details can be found at [1].

There are few simplifications in our model in comparison to [4]. Steffen and Hotchkiss assumed that every passenger need free space (width of one seat on each side) while loading luggage. Their *Steffen* method was designed to be efficient with respect to this assumption. Our model permits directly adjacent *passenger-agents* to stow their luggage with no delay. In case of back-to-back stowing passenger-agents the storing time is extended according to the current parameters' setting.

4 Experiments

Multiple experiments with different combinations of *use-random-seed*, *boarding-method*, *passengers-with-luggage*, *delayed-people* and *luggage-loading-time* parameters were performed. Details can be found at [1]. Here we present two experiments: basic comparison of boarding methods and the measurement of the effect of late passengers.

4.1 Experiment A – comparison of boarding methods

We run the simulation 200 times for every method to eliminate the influence of the random seed generator. The mean time (measured in *ticks* of internal NetLogo clock) is presented in graph (Fig. 3). The *Kautzka 3* method is very fast. This combination *Wilma*, *Back front* and *Steffen* method eliminated all intersections in seats and aisle and it enabled parallel luggage stowing. Moreover it allowed boarding in pairs, without unrealistic splitting families of pairs of passengers.

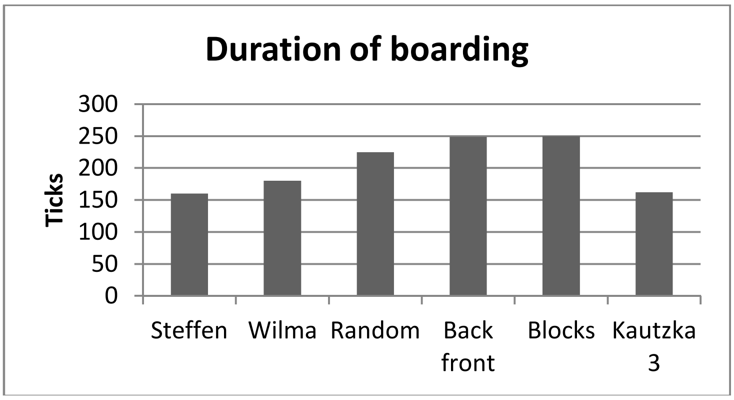

Figure 3: Comparison of all methods

4.2 Experiment B – the impact of late passengers

The disadvantage of *Steffen*, *Back-front* and *Kautzka 3* methods is the expectation of passengers to be punctual and disciplined outside the aircraft. The next experiment was focused on this aspect. We measured the impact of late passengers who could not be arranged into their places in the queue. We tested the influence of 0, 10 and 20 percent late passengers. The results are presented in graph (Fig. 4).

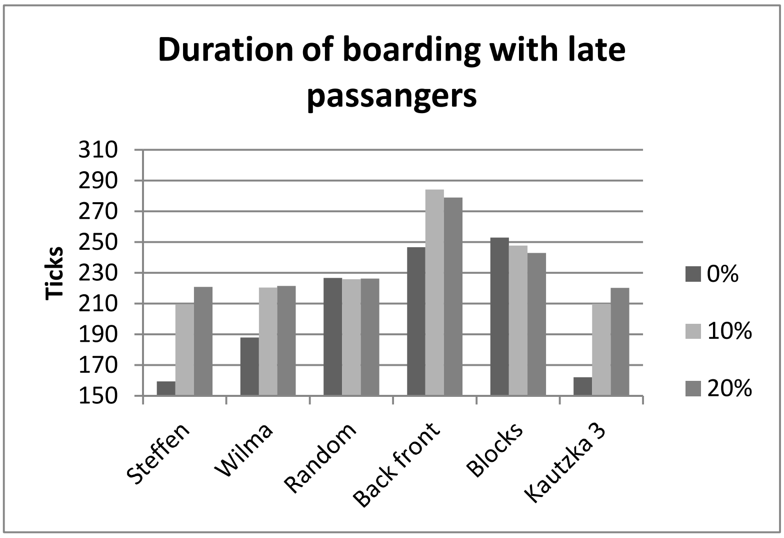

Figure 4: The impact of late passengers

We found that having 10% late passengers, the boarding times prolonged significantly. The *Steffen* and *Kautzka 3* methods are very sensitive to late passengers. Methods *Wilma* and *Back-front* are not so sensitive but there is still increase of average 15%. As we can expect number of late passengers does not change results of the *Random* method. Surprisingly the boarding time for *Blocks* method decreased if number of late passengers increased. The increasing number of late passengers gradually changes the *Blocks* method into the *Random* method which has better results.

Significant increase of boarding time for *Steffen* and *Kautzka 3* methods is caused by increasing number of aisle and seat interferences. Already 10% of late passengers worsen results of *Steffen* and *Kautzka 3* nearly to the *Random* method boarding time.

5 Conclusion

Agent-based modelling is a powerful tool for the analysis of aircraft boarding methods. Our NetLogo implementation of boarding model can be extended easily. It is possible to add new boarding methods as well as to change the size of the plane. We confirmed results of Steffen and Hotchkiss. Moreover we presented an innovated method *Kautzka 3* which improves the Steffen's method by managing groups of passengers who travel together (families, colleagues). Theoretically the usage of sophisticated boarding methods can shorten aircraft preparation for departure. Practically the requirement of precise arrangement of passengers at the gate does not seem to be realistic because passengers are not used to it. Designing of serviceable methods of arranging passengers could be objective of further research.

Acknowledgements

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