THE AIRLINE BOARDING PROBLEM: SIMULATION BASED APPROACH FROM DIFFERENT PLAYERS' PERSPECTIVE

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***Abstract**: In order to sustain profitable growth, it is crucially important for both airports and airlines to revise possibilities to reduce tournaround time, as one of the most significant factor that highly influence total cost of airlines and efficiency of airports. Although boarding time as a part of turnaround time is not the major contributor of delay of an airplane, it is evident that has more opportunity to be altered compared to other components in turnaround time set. In this paper we developed a simulation model that investigates different boarding patterns, in order to detect the most efficient one, from different players' perspective, by taking into consideration mainly individual boarding times. The results are analyzed with regard to airline objectives as well as to customer objectives, and some of the implementation issues are also being considered.*

Keywords: *Simulation, Boarding strategy, Airline boarding process, Transportation, Boarding times.*

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1. INTRODUCTION

Over the last few decades, the demand for air transportation has grown rapidly. Use of hub-and-spoke systems has been increasing, causing a high number of airplanes to arrive at the hub airports within a few hours. In order to avoid airport congestions, which can cause delays, but also to increase operational efficiency, airlines are continuously in a search for new ways to reduce turnaround time. By minimizing turnaround time airlines can increase aircraft utilization, which generates revenue. They do not generate any revenue while aircraft is on the ground. Thus, the reduction in airplane turnaround time is a crucial factor that has direct impact on reducing the costs of an airline. Airplane turnaround time is defined as "the time required to unload an airplane after its arrival at the gate and to prepare it for departure again". It consists of actions such as deplaning, cargo unloading and loading, fuelling, cabin cleaning, galley servicing and enplaning (boarding). Moreover, airline is solely involved in the process of boarding which allows creating the most efficient strategy itself. Compared to other components in turnaround process that are very straightforward, boarding component can be subject to modification and alteration to a certain level. Furthermore, because of safety and operational constraints, passenger boarding is the last task performed in this timeline. In other words, any time saved through efficient boarding directly reduces the turnaround time. Consequently, airlines currently strive to achieve more effective boarding process pattern.

In last decade, significant scientific and airline industry expert efforts have been dedicated to airline boarding issue. In addition to financial losses that can occur due to inefficient boarding process, it can also lead towards poor passengers' perception of airline service quality. Several strategies adopted by many airlines nowadays, especially those in United States, have been recently proposed by group of academics.

The leading work by Van Landeghem and Beuselinck emphasize the importance of revision of traditional boarding strategy used by many airlines [9]. The authors identified seven boarding models to include random, by block, by half-block, by row, by half-row, by seatgroup, and by seat. According to these authors, boarding times can be extended by interruptions that occur during seat interference, aisle interference or lack of overhead bin vacancies. Seat interference occurs when passenger's seat is closer to the window than another passenger nearer to the aisle in the same half-row already seated. In that case, the seated passenger rise and move back into the aisle to allow the other passenger access to his seat. On the other hand, aisle interference occurs when one passenger is obstructed by another passenger who is stowing his luggage, seating himself, or obstructed himself. In such situation, the first passenger must wait behind the other passenger until removes himself from aisle or moved forward. The most time-consuming congestion component identified by Van Landeghem and Beuselinck was storing carry-on luggage. This type of delay occurs when a passenger needing to stow their luggage in overhead bins cannot do so because the overhead bins near his seat are full. Thus, the passenger must then move either upstream or downstream in an attempt to find a vacancy for his luggage. Final conclusion of these two authors reveals very strong correlation between total boarding time and average individual boarding time. In other words, the strategies applied yields the fastest individual boarding time and therefore higher level of passenger satisfaction. Reverse pyramid is boarding strategy that was initially developed by Van den Briel et al. in order to reduce boarding time in American West Airlines [8]. Reverse pyramid strategy calls for simultaneously loading an airplane from back to front and outside-in – window and middle passengers near the back of the plane board first and those with aisle seats near the front are called last. Relying on the previous work by Van Landeghem and Beuselinck, Ferrari and Nagel define the model that calculates time associated with storing carry-on luggage as a function of the number of bags already in the bin plus the number of bags being carried by each passenger [4]. The model fails to account aisle interference that occurs once a bin has reached capacity and passenger must move along the plane in search of open bin space. Bazargan introduces a new mixed integer linear program to minimize the total number of passenger interferences [2]. The recommended efficient solutions are more appealing to both airlines and passengers as they can accommodate neighboring passengers to board together. Bachmat and Elkin provide bounds on the performance of back-to-front policy can be more than 20% better than the policy which boards passengers randomly [1]. Steffen finds the passenger ordering that minimized the time required to board an airplane by employing Markov Chain Monte Carlo optimization algorithm [6]. The entire idea of an optimized boarding strategy focuses on spreading the passengers who are loading their luggage throughout the length of the airplane instead of concentrating them in a particular portion of the cabin. Tang et al. develop a new aircraft boarding model with consideration of passengers' individual properties and then design three different aircraft strategies and used proposed model to explore the aircraft boarding behavior under the three aircraft boarding strategies [7].

Boarding process was comprehensively examined by world leading aircraft manufacturer – *Boeing*. Boeing began using discrete event simulation to understand interactions in the factory environment. In 1994, Boeing started applying the discrete event model in passenger boarding studies. PEDS (*Passengers Enplane/Deplane Simulation*) assigns each passenger certain attributes, such as walking speed, type of carry-on luggage, luggage put-away time, and relationship with other passengers (traveling alone or with a group) [3]. The simulation accounts for random behavior by applying probability distributions to passenger attributes.

Strategies adopted by mainly U.S carriers are presented in Table 1 [5].

Table 1. Boarding strategy used by airline

Boarding Strategy	Airline
Outside in	United
Random	Southwest, US Airways
Back to Front	Air Canada, Alaska, American, British Airways, Continental, Frontier, JetBlue, Spirit, Virgin, Atlantic
Reverse pyramid	US Airways (America West)
Rotating zone	AirTran
Zone/Block Style	Delta

As it is shown in Table 1. many airlines including Continental, American and JetBlue board back to front. Furthermore, United refers to their outside-in boarding process as *Wilma* (Window, Middle, Aisle). This outside-in system boards all window passengers first, followed by those with middle seats and finally, those seated in the aisle. Southwest does not assign seats, while US Airways has relatively random seating, though the airline does give preference to certain passengers, including elites and those who check in online. AirTran Airways launched a boarding system named as a rotating zone system. AirTran first seats the five back rows of the plane, then the front five, and continues rotating back-front-back until boarding is complete. By employing this strategy, AirTran reduce turnaround times in the 20 to 30 minute range. Delta groups passengers into as many as nine zones which have different order od priorities.

In this paper we developed simulation model for a single aisle airplane. This model takes into account both airline and passenger's boarding time, that is the main contribution of this paper.

2. BOARDING PROCESS

Generally, the actual boarding process consists of the following three steps:

1) Passengers are called to boarding by gate agent. If certain strategy is applied, they are called to board in exact sequence. At this time passengers start queuing at the gate, while gate agent controls the boarding pass of each passenger.
2) Passengers resume their movement towards the airplane, usually through the access bridge, but in some cases they might be transferred to the airplane by bus.
3) Finally when passengers access the airplane, they yet again form a queue, within single aisle airplane until they reach their seats. Within the airplane, several interferences and delays may occur as a result of passengers' behavior, which we detail below. When they reach their row, passengers need to stow their luggage in the overhead bin compartment, but they also block the aisle while doing so. After completion of such action, unless there are no seat interferences, passenger can finally sit. Otherwise passenger that blocks the way has to get up from his seat and let him pass.

3. COMMON STRATEGIES

Call-off-systems, also named boarding strategies, are of crucial importance in controlling the flow of passengers onto the aircraft. In our observations we found that various airlines impose different boarding strategies, based on airline culture and service level. Our model investigated only 3 strategies, Back to Front (BF), Random (RDM) and Out-in (OI) boarding strategy. These three were selected as fundamentally different, while the others can be subsumed under, as a variation or a combination of these categories.

Back-to-front (BF) boarding strategy, is the most common boarding technique. It divides passengers into groups, which are then called to board the airplane in sequence, starting from back of the airplane towards front, as the name implies.

In random (RDM) boarding strategy, no specific strategy is used. All passengers belong to a single boarding group, and they enter into the airplane randomly. This boarding process is often used as a baseline for comparison to other models.

Out-in (OI) boarding strategy, also called window-middle-aisle boarding strategy, divides passengers into three groups. As the name implies, passengers who are seating in window seats boards first, than middle seat passengers, and finally in the third group are those passengers who seat in the aisle seats. In previous research it was found that OI strategy was among the most efficient boarding strategies.

4. SIMULATION MODEL

We focused our study to Short Haul flights, which typically use airplanes with seating capacity between 80 and 150. We modeled airplane with 120 seats, divided into (n=20) rows. Influence of First class, frequent flyer and passengers with disabilities, who in practice always boards first, was disregarded in this model.

In this paper, we simulated only the movement of passengers inside the aircraft, which basically means that Steps 1 and 2 of boarding process were disregarded. Yet, since the stream of passengers that enters the airplane doors depends on gating operations (the rate at which gate agent checks boarding passes), we simulated this action as well. The model assumes passengers arrive at the airplane at the rate that is normally distributed around mean μ= 5 seconds, (σ=2 seconds). Each passenger was randomly assigned to a seat on the plane, but randomization was adapted according to strategy in use. Passenger movement throughout the aisle was simulated by time it takes them to pass 1 row of seats, for which, triangular distribution (Min=1.8 seconds, Mode=2.4 seconds, Max=3 seconds) was used. Passenger movement depends on various interferences. It also depends on their interactions with other passengers, which means that the passenger will move forward only if the next row is clear.

Seat interferences in the model occur as a consequence of randomized sequence in which the passengers board the aircraft. The time needed to resolve such a conflict was simulated with triangular distribution (Min=3 seconds, Mode=3.6 seconds, Max=4.2 seconds). Seat interferences may also cause aisle interferences, as they usually do.

Aisle interferences can occur during an action in which passengers stow their luggage, as well. Duration of this action depends on the number of carry-on luggage involved and this model assumed that 25% of all passengers carry-on 2 bags, 50% carry-on 1 bag, while 25% does not carry-on any bag at all.

The model calculated the time factor, associated with storing carry-on luggage by evaluating the number of bags already in the bin. Calculated time factor (T) is then multiplied by the number of carry-on bags being carried by each passenger. To determine values of time factor (T), associated with storing carry-on luggage, we used Weibull cumulative (k=4, λ=80) distribution function as a measure of additional time it takes to load luggage as the plane fills up. We considered this distribution as the most appropriate among many others which are currently used in the literature since it takes into account the main features of storing luggage process in overhead bins. The expression for the calculated time factor (T) for passenger, who carries x-th bag into the airplane, is calculated with the equation (1),

$$T = c * F(\boldsymbol{x}, \boldsymbol{k}, \boldsymbol{\lambda}) + n \qquad (1)$$

where c- (24 seconds) is a measure of the additional time we would expect someone to take to store baggage when the overhead bin is full, F(x, k, λ) is the Weibull cumulative distribution function and n- (6 seconds) is a minimal time required to store the luggage.

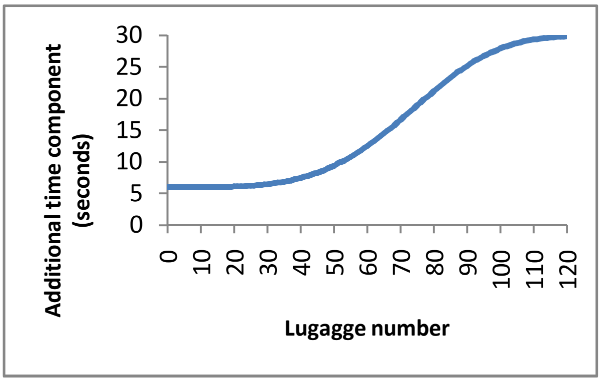

Figure 1. Cumulative distribution function of a Weibull distribution

As Figure 1 shows, obtained function has sigmoid shape, consistent with our baggage loading process. When there are few bags in the airplane, time required to load the luggage is relatively small (around 6 seconds). As the number of bags increases, this time increases slowly when there is still a lot of space and then rapidly as people start having to rearrange compartments to fit their luggage. When overhead compartment reaches its full capacity, the difference in time required to find space for baggage becomes minimal as most baggage bins have relatively little space left.

In order to review effectiveness of various strategies from different perspectives, we developed simulation model that simulates passenger boarding process. The boarding procedure has been simulated and analyzed using GPSSH simulation software. Simulation model that we proposed consists of several consecutive steps:

- Start – in this block, the stream of passengers that have been generated,
- Assignment of input parameters – number of seats, passenger movement, time for storing carry-on luggage, group of passengers, time for storing carry-on luggage in the case of seat interference,
- Time measuring block,
- Assignment of the row to each passenegrs who enters the system – the purpose of this block is to simulate movement of passenger through the plane,
- Assignment of the seat to each passenegrs,
- Print the output results,
- End.

5. RESULTS

Our main goal has been divided into two sections. First task was to determine the most efficient strategy from airlines perspective. Second goal was to determine the most efficient boarding strategy from passengers' perspective.

Total boarding time is clearly important from airlines perspective, since it determines the airplane turnaround time. Therefore we analyzed the total boarding times for, above mentioned, scenarios. The results that represent the average from 20 realizations are shown in Figure 2. In each realization, for every passenger, personal characteristics, such as their seat number, speed, luggage loading time, and time to resolve seat interferences, were randomly altered.

As shown in Figure 2, in regard to total boarding time, BF strategy performed worst with an average of μ=24.61 minutes. RDM strategy performed very well with μ=19.02 minutes in average, while OI was shown as the best, as it lasted μ=17.51 minutes in average.

We also measured standard deviation which showed that data from BF strategy is widely spread, making this strategy less reliable (σ=2.72 minutes), than the other two. Value of standard deviation for RDM strategy were clustered closely around the mean σ=1.90 minutes, while results for OI strategy performed even better, because they tend to be even closer to the mean (σ=1.78 minutes).

Better results of RDM strategy versus BF strategy can be explained by the fact that RDM strategy uses the aisle space more efficiently since more passengers who enter the airplane can put their luggage in parallel. In this manner the aisle is not used as a passive extension of the waiting area, but rather as a place for passengers to actively situate themselves. On the other hand in BF strategy only the first few would be putting their luggage away while the others have to wait their turn, meaning that passengers would load their luggage serially. By doing so, BF strategies prolong the passenger boarding process. In OI strategy, passengers can also put away their luggage in parallel as the RDM strategy, but it also eliminates all seat collisions from the boarding process, and by doing so it performs even better than the RDM strategy.

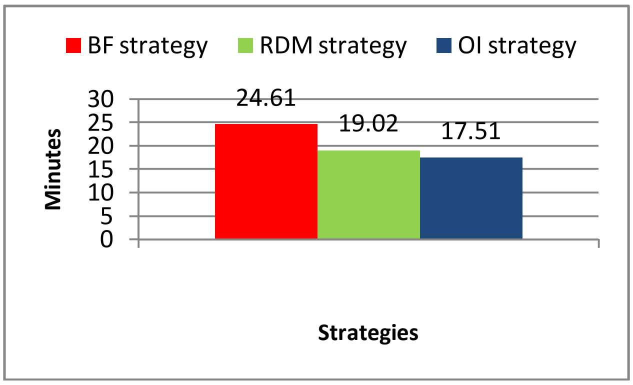

Figure 2. Total boarding times, for different strategies

However passengers are more susceptible to the waiting times they experience personally. Therefore, we also examined individual boarding times for each passenger from 20 realizations.

Our founding was implying that very high correlation between total boarding time and average individual boarding time exists, as could be expected. It means that strategies which performed really badly when it comes to total boarding times, such as BF strategy, also generate long individual boarding times. In our model, for example, individual boarding time, via BF strategy, lasts in average μ=4.59 minutes, per passenger with standard deviation σ=4.15 minutes. We also noted that RDM strategy performed surprisingly better then BF strategy with individual average time μ=2.74 minutes, and standard deviation σ=2.44 minutes. Fastest method (OI strategy), as could be expected, also yields the best passenger comfort since it generates lowest average μ=2.29 with standard deviation σ=2.00 minutes.

Since the average values alone, didn't provide us with enough information about boarding process from passenger's perspective, we further analyzed results. More detailed information on individual boarding times for each strategy is displayed in Figures 2, 3 and 4.

In order to present our founding's more clearly, we introduced certain assumptions into our analysis. We assumed that passenger would be satisfied if they board the airplane within 4 minutes. On the other hand if individual boarding lasts more than 10 minutes, it is considered as unacceptable, since it reduces, in great deal passengers' perception on service quality.

If airline chooses to implement BF strategy, nearly 60% of its passengers would board the airplane within 4 minutes, while 14% of them would be unsatisfied since they need more than 10 minutes to reach their seats. Figure 3 illustrates distribution of individual boarding times in percentage.

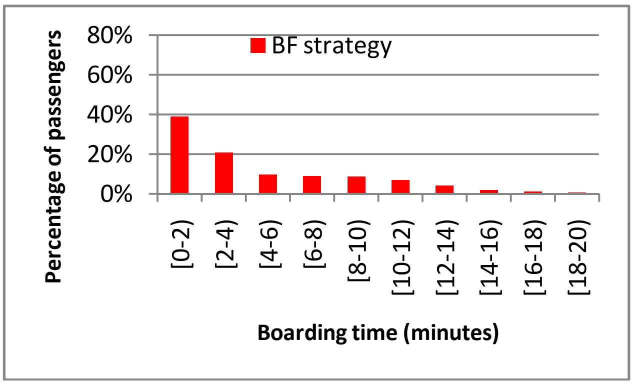

Figure 3. Relative frequency distribution of individual boarding times for BF strategy

With RDM strategy, around 74% of its passengers would board the airplane within 4 minutes, and the percentage of passengers that falls into "unsatisfied" category is slightly above 1% as it can be seen in Figure 4.

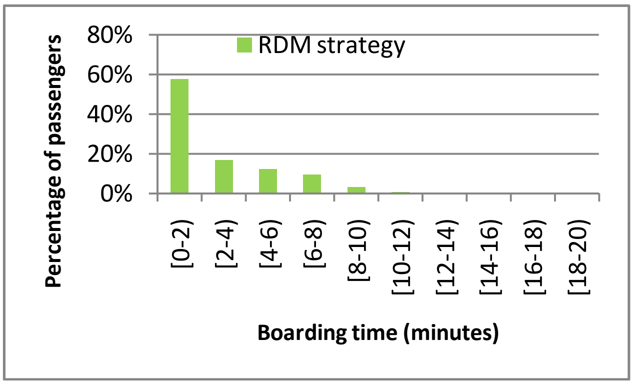

Figure 4. Relative frequency distribution of individual boarding times for RDM strategy

Greatest passenger satisfaction can be achieved with OI strategy (Figure 5). Around 81% of passengers can reach its seats within 4 minutes, while the number of "unsatisfied" passengers is negligible.

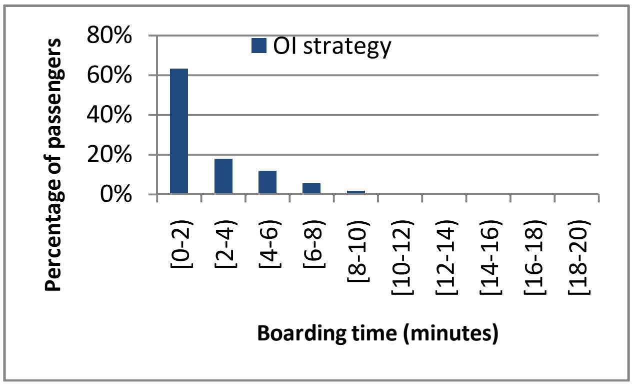

Figure 5. Relative frequency distribution of individual boarding times for OI strategy

6. CONCLUSION

In this paper three different boarding patterns have been examined in order to investigate their efficiency from both airlines and passengers' perspective. For that purpose, new simulation model of boarding process was developed. Total boarding times were measured as metric of efficiency from airlines perspective, while individual boarding times represented boarding efficiency from passengers' perspective.

Findings indicate that there is a strong correlation between total and individual boarding times as could be expected. Nevertheless, study showed that by investigating individual boarding times one can get better insight into the overall boarding process. In other words they need to be included into analysis in order to gain more detailed information about the effects that any change has on a boarding process.

Surprisingly, study showed that RDM strategy is far more effective than BF strategy commonly used by many airlines around the globe. In addition to that RDM strategy is much easier to implement, since no regulation of process is needed. Although OI strategy outperformed the other two in each aspect, its implementation issues might be an obstacle which cannot be surpassed. Separation of passengers who are traveling together, during the boarding process, for example might be unacceptable for many of them.

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