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Improving airplane boarding time: a review, a field study and an experiment with a new way of hand luggage stowing

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Cover Page Footnote

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Many of us have personal experience of airplane (de)boarding. We may have observed that this process of getting passengers into or out of an airplane is not organized optimally – a fact confirmed by the literature (e.g., Nyquist and McFadden, 2008). Computer simulations indicate that there are more efficient boarding methods than those currently in use (e.g., Landeghem and Beuselinck, 2002). However, the implementation of such optimal boarding schemes presents specific practical challenges (Steffen, 2008). As well as the passenger experience, boarding also influences airplane turnaround times (the time between arrival and departure of an airplane). The theoretical duration of a full turnaround for a Boeing 737-900 is 45 minutes, while a short turnaround takes 23 minutes (Kierzkowski & Kisiel, 2017). A full turnaround includes activities such as crew replacement, servicing the galleys and cabin, refuelling, servicing toilets and water, passenger (de)boarding and baggage (un)loading, while a short turnaround includes only passenger (de)boarding and baggage (un)loading and is feasible using two sets of stairs.

Shortening the turnaround time is beneficial for the airline, as it prevents delays and avoids losing the slot. Air traffic control allocates a slot to an aircraft, stating when it can take off. If the aircraft cannot achieve this take off time, it must reapply for a new slot, which usually results in a delay. Boarding improvements hence take effect in two areas: passenger experience and turnaround time. This leads to our research question: Which factors enhance passenger experience and reduce boarding times? To answer this question, a literature review of scientific studies relating to boarding is done. Additionally, observations of different real-life boarding scenarios are made, and a pilot test of a potential improvement to the boarding process is carried out.

Literature Review

A literature search was carried out to study factors relating to boarding time duration and passenger experience. On January 29, 2017, papers were selected using the search terms "boarding" AND "airplane" in Scopus and Google Scholar. A paper was selected if the search terms appeared in the title, keywords or abstract. Additional papers were selected from the reference sections of papers matching the search terms. Selected papers were then filtered for mentions of boarding time or passenger experience. Papers not directly addressing these criteria were excluded (e.g., papers on train boarding, personal identification, fear of flying and adaptations for persons with reduced mobility). The search uncovered 46 papers, of which 28 reported on boarding time or passenger experience. The types of boarding mentioned in these 28 papers were then determined (e.g., back-to-front, random, double entry), and the effects of each were studied. If a specific method resulted in faster boarding, this was marked as an 'interesting result.' The method of study (simulation, optimization, observation, or other) was noted, and a list of related problems and possible solutions compiled. A study is classified as a simulation study when a model is expressed as a computer program, which runs some times with different input data whose results can be compared. A study is classified as model optimization when the focus of the paper is on improving existing models. Experiments involving participants are noted as such. The present study describes promising improvements for boarding that are mentioned in more than four papers.

Twenty-eight papers were selected for further analysis. The eight most frequently discussed boarding schemes for airplanes using one jetway (7 out of the 28 papers) for a 3-3 configuration (three seats on either side of the aisle) are also described by Steffen (2008). These are:

1. Random: passengers board as they wish. This can be done with and without assigned seats;
2. Back-to-front: there are three groups. The back third boards first, then the middle third, and finally the front third (this can also be done with four or five groups);
3. Block boarding: the rear zone boards first, then the front zone, and finally the middle zone.
4. Outside-in: the passengers with window seats board first, then those with middle seats, and finally those with aisle seats;
5. Outside-in + back-to-front, which is a combination of types 2 and 4;
6. Back-to-front, skipping a row, with window seat passengers boarding first (also called the Steffens' Method): window seat passengers board first, using back-to-front boarding, with a row skipped each time;
7. Reverse pyramid: columns are defined within the airplane, and boarding starts with window columns in the back and ends with aisle columns in the front.
8. Two-entry boarding: the front and rear doors are both used for boarding.

The outcome of information taken from the 28 papers is summarized in Table 1. The three issues regarding boarding time and passenger experience mentioned in more than four papers are random boarding, reverse pyramid boarding, and hand luggage.

Random boarding

Five papers state that random boarding is faster than other boarding methods. In their simulation, Ferrari and Nagel (2005) found that random boarding was faster than block boarding. Bauer et al. (2007) found that random boarding with no assigned seating performed best among the other methods. Mas et al. (2013) stated that random boarding performed best in most scenarios. Both Jaehn and Neumann (2014) and Qiang et al. (2014) found that random boarding was faster than back-to-front. All five papers were based on simulations, not real-life observations.

Pyramid method

Five papers found that the reverse pyramid method (sometimes called the pyramid method) was faster than some other boarding methods. Briel et al. (2003) showed that for the total expected number of aisle interferences, outside-in and reverse pyramid boarding performed better than all other strategies. Briel et al. (2005) affirm this in another paper. As stated above, Bauer et al. (2007) found that random boarding with no assigned seating was fastest, while the pyramid method performed best when there was assigned seating. Nyquist and McFadden (2008) state that increasing the number of doors or using the reverse pyramid method could save airlines millions of dollars per year. Qiang et al. (2014) showed that the pyramid strategy was better than both random boarding and the back-to-front method. However, their simulation also revealed that the Steffen Method and their self-developed boarding scheme were faster than the pyramid method. All these papers based their findings on simulations, not real-life observations and the outcomes are influenced by the way the simulation is modelled.

Table 1
Method used and interesting results by paper

Author(s)	Literature review	Model optimization	Model simulation	no. of participants in experiment	Interesting results
Muir et al., 1996				1,558	Larger space between rows increases evacuation speed
Marelli et al., 1998			x	600	2-door boarding saved 5 minutes (B757). Unexpected behavior: passengers stowing carry-on luggage in overhead lockers distant to their seats
Landeghem and Beuselinck, 2002			x		Some discrepancy between current practices and optimal patterns. Descending by row and by letter (23A, 22A, 21A, etc.; 1A, 23B, 22B, 21B, etc.) is 100% faster than random boarding
van den Briel et al., 2003			x		Structured group boarding (pyramid) can result in boarding time reductions
Ferrari and Nagel, 2005			x		Block strategies prolong the boarding process compared with random boarding
Bachmat et al., 2005			x		The ideal boarding method is dependent on the aircraft interior
Briel et al., 2005			x		Window to the aisle (pyramid) results in the least interference
Bauer et al., 2007			x		Random boarding with no assigned seating performs best. Assigned seating, outside-in, and the pyramid method are faster
Bachmat et al., 2007		x			A typical modeling approach is presented
Nyquist and McFadden, 2008	X				Using more doors or the reverse pyramid method reducing passenger interference, managing carry-on luggage, and loading passengers into the aircraft using two doors could save airlines millions of dollars per year. The latter saved 5 minutes for an A320/B737
Bachmat and Elkin, 2008			x		Back-to-front boarding can be 20% better than random boarding

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Author(s)	Literature review	Model optimization	Model simulation	no. of participants in experiment	Interesting results
Steffen, 2008			x		Allowing several passengers to load their luggage simultaneously reduces boarding times, as does the window-to-aisle method
Bachmat et al., 2009			x		The outside-in method is a good boarding policy. Adding passengers per row or shortening the distance between rows causes the boarding process to become slower
Steiner and Philipp, 2009			x	x	Less hand luggage and use of the pre-boarding area can reduce boarding time by 4 minutes for an A321
Steffen and Hotchkiss, 2011				72	More passengers stowing their luggage simultaneously leads to quicker boarding. Aisle blocking is the main problem
Tang et al., 2012			x		Seat assignation based on personal speed and carry-on luggage (fast and least loaded first) is faster
Soolaki et al., 2012		x			model improvement
Brics et al., 2013		x			model improvement
Baek et al., 2013		x			model improvement
Mas et al., 2013			x		The random boarding strategy seems to perform best in all scenarios
Bachmat et al., 2013			x		As congestion increases, random boarding becomes more attractive
Jaehn and Neumann, 2014	x				Back-to-front boarding requires more time than random boarding
Milne and Kelly, 2014			x		Assigning individual passengers to seats based on the amount of luggage they are carrying is faster
Cadarso et al., 2014			x		The alternative rows strategy is superior
Kierzkowski, 2016			x		A model was made of an A320 and compared with the literature results

Author(s)	Literature review	Model optimization	Model simulation	no. of participants in experiment	Interesting results
Miura and Nishinari, 2017				66	High-density perceived boarding time is shorter, while block boarding is faster
Kierzkowski and Kisiel, 2017				>5,000	Different hand luggage stowing times are presented in different scenarios

Hand luggage

Seven papers mention that hand luggage affects on boarding time. Marelli et al. (1998) state that stowing carry-on luggage in overhead lockers distant to seats influences boarding time, as passengers sometimes have to walk against the flow. Steffen (2008) describes how allowing several passengers to load their hand luggage simultaneously reduces boarding time. Steffen and Hotchkiss (2011) make a similar point. Based on results from both simulation and observation, Steiner and Philipp (2009) state that boarding with less hand luggage is faster. Tang et al. (2012) use simulation to support the statement that assigning seats based on personal speed and carry-on luggage (fastest passengers and those with least luggage first) is faster. Qiang et al. (2014) show that the Steffen Method, in combination with giving priority to passengers with the most hand luggage, is somewhat fast. This method is also the most stable, with low variation in boarding times – an important factor for airlines. Milne and Kelly (2014) assigned passengers to seats so that their luggage was evenly distributed throughout the airplane. This was the fastest method for a fully loaded aircraft. In their observation of more than 5,000 low-cost passengers, Kierzkowski and Kisiel (2017) saw luggage stowage as a significant problem, with boarding speed dependent on the way that passengers stowed their luggage. Stowing hand luggage while standing next to the aisle (possible with an empty aisle seat) is faster than when standing in the aisle. Stowage is also faster if the overhead lockers are less than 50% full. Hand luggage data are based both on simulation and passenger observation (e.g., Marelli et., 1998; Steiner & Philipp, 2009; Kierzkowski & Kisiel, 2017).

The literature review shows that most of the papers involve simulation studies, with outcomes dependent on the type of simulation used and the way in which the different factors are modeled. The reverse pyramid method has also been applied in practice to positive effect (Vincent, 2016). Hand luggage stowage is an essential factor in lowering boarding times, as it can lead to the aisle being blocked. However, variations in ways of stowing luggage are not considered in simulations, aside from those of Kierzkowski and Kisiel (2017). Simulation outcomes are also dependent on whether the focus is on achieving the fastest boarding method or the method with the least variation (and thus the highest predictability) in turnaround times. Interestingly, many of these studies show that random boarding is not the worst method, and the reverse pyramid or Steffen Method also perform well. Luggage stowage receives significant attention in the literature as a factor influencing boarding times.

Method

Three field observations were performed for three different flights. This was a complex process, requiring permission from the airline (management, local union, and crew), the airport and airport security. The observation was thus limited to three flights. Two of these were within Europe, where boarding times are critical (3-3 conFigureuration aircraft). The other was an intercontinental flight, where the area with the (3-4-3 conFigureuration could be observed. For the two continental flights, facing cameras were positioned above the aisle in the front and back of the airplane to capture the behavior of the passengers. The intercontinental airplane, however, was too big to be fully captured by two cameras. Here, two parallel cameras were positioned facing front to observe the two aisles. The crowded rear section was considered the more interesting part of the airplane to film. The passengers were not aware of the cameras, and only one researcher was allowed to watch and study the video. Reports were only allowed to use group results and were prohibited from mentioning individuals. The video recordings were used to study passengers' behavior and count the number of interferences. The following two types of interference with an impact on boarding times were recorded: seat interference and aisle interference (Briel et al., 2003). Seat interference occurs when a passenger has to get out of their seat row to let another passenger pass. Aisle interference occurs when someone is blocking the aisle. The time waiting at the first seat row (entry to the airplane) was also recorded, and leading causes of these interferences were described.

Results

Video footage was taken of 292 passengers in two narrow-body jets (B737-7 and B737-8), and 244 passengers in one wide-body jet (B777). In the wide-body aircraft, a lack of cameras meant that not all passengers were able to be filmed. For the narrow-body aircraft, 108 aisle interferences and 29 seat interferences were observed, resulting in a total of 12:32 minutes waiting at the first row. Of these, 101 aisle interferences were caused by hand luggage storage, and the aisle was blocked due to a person leaving their seat to let another passenger get to his/her seat on seven occasions.

Table 2
Recorded data for the three boarding scenarios

Airplane	737-8	737-7	777-2
Capacity	175	150	316
Passengers	162	130	244
Boarding time	22:15	16:24	16:44
Aisle interference	68	40	unknown
Seat interference	18	11	unknown
Waiting time at first row	7:44	4:48	unknown

Aisle interference can be divided into self-centered and environment-focused interference. Environment-focused aisle interference means that people pay attention to what is happening around them and allow other travelers to pass (see Figure 1, left). Self-centered aisle interference happens when a traveler, for instance, places his/her bag and laptop case into the overhead lockers, blocking the aisle while others wait (see Figure 1, right). This can happen both consciously and unconsciously.

Figure 1. Left: aisle interference where one passenger allows another to pass (social). Right: aisle interference where a passenger blocks the aisle (anti-social).

Additional handling (second interference) is sometimes needed for luggage storage. This could be prevented by improved preparation. Travelers sometimes stow their hand luggage at a 90-degree angle, which occupies more space in the overhead lockers. This may lead to additional aisle blocking when the flight attendant intervenes to position it correctly. Passengers may also block the aisle when stowing their jackets or retrieving things for use during the flight (e.g., a book or a laptop) from their stowed hand luggage. If the overhead lockers are full, flight attendants may remove the jackets and small bags and ask passengers to stow them underneath the seat in front of them. Our observations revealed this practice to be a source of discussion or even irritation among passengers. Ultimately, there is not enough space for hand luggage in the overhead lockers. Extra work is thus required by the flight attendants to place the bags on wheels away from the seat, as mentioned by Marelli et al. (1998). Sometimes passengers have difficulties in finding their seat, as the seat numbers are small and difficult to make out. This causes people to slow down or take the wrong seat, blocking the aisle and row when the error is discovered, and they are re-seated.

Discussion

The two types of interference recorded by Briel et al. (2003) were present in our observations. The majority of aisle blocking is caused by luggage stowage (101 out of 108 times). In an almost full Boeing 737-8, 68 instances of aisle blocking were observed (ratio of 0.42 (68/162)), while in an emptier Boeing 737-7 with 87% of the seats occupied, the ratio was 0.31. Briel et al. (2005) observed between 78 and 87 instances of aisle blocking for an A320 with all 150 seats occupied (a ratio of 0.53). More than half of the passengers were temporarily blocked while walking along the aisle. We can hence conclude that instances of aisle interference increase with the number of passengers on the aircraft. Based on their observations of 5,000 passengers, Kierzkowski and Kisiel (2017) showed that seat interference did not influence total boarding time in 30% of cases. In a study by Briel et al. (2005), the number of seat interferences varied greatly, with between 3 and 73 instances for 150 passengers, depending on the boarding method used. The 11 and 18 seat interferences in the present 30-passenger study are within this range. However, Briel et al. (2005) also reported that the effect of aisle interference was much greater. Nyquist and McFadden (2008) also showed the significant impact of hand luggage stowage on boarding time, estimating that the time saved by eliminating all hand luggage would be 11 minutes for a flight with a boarding time of 20 minutes.

The total boarding time for an entirely occupied A320 is between 16 and 23 minutes, depending on the boarding method employed (Briel et al.,2005). This range is comparable to the boarding times observed in this study. Similarly, Steiner and Philipp (2009) reported a boarding time of 23 minutes for 160 passengers in an A320 with a maximum capacity of 162 passengers. The fact that only two narrow-body airplanes were observed is a limitation of the present study. However, observed boarding times are comparable with those in the literature, and the impact of hand luggage stowage is confirmed by other studies.

Improvement pilot test

Method

Both the literature and the observation described above indicate that luggage stowage increases boarding times. For this pilot test, 15 industrial design master's students were asked to develop solutions for luggage stowage (the developed solutions were for instance, increasing the space under the seat; training passengers; placing all hand luggage in the hold). Nine representatives of three airlines employing narrow-body jets were then asked to select the most promising idea. The winning proposition consisted of first defining the dimensions of the hand luggage and then calculating the most efficient way for it to be stowed. Smartphone apps exist for calculating baggage size from a picture (next to an A4 sheet of paper for calibration). When the picture is uploaded, the airline can then give feedback (by software) about whether the hand luggage is allowed on the plane. This information could reduce the stress of boarding, as passengers would know that there is space for their hand luggage and not feel compelled to rush. However, it remains a matter of debate whether the predefined placing of hand luggage is faster and has a positive impact on passengers' experience.

A pilot test was carried out to determine the impact of the proposed solution. Thirty passengers (age 20-30 years; 13 females, 17 males; 70% from the Netherlands, 30% from the rest of the world) were asked to board a Boeing 737 on four occasions. Participants were assigned five rows of six seats, with three overhead lockers located exactly above the seats on each side. Hand luggage was selected and measured, and the optimal storage was calculated. Participants were given different types of hand luggage with dimensions close to 40x50x25 cm. Each of these was loaded with approximately 5 kg sandbags. A different seat was assigned for each of the four boarding events. The first time, passengers boarded at random. An assigned seat was shown on their boarding pass, but no order for boarding and no instructions for stowing hand luggage were given. The second time, an assigned seat was shown on their boarding pass, the seat number was now shown in the overhead locker as well indication the assigned position in the overhead locker (see Figure 2). The third time, passengers boarded at random with a different assigned seat. Moreover, the fourth time, passengers were given an assigned position in the overhead locker. All 30 subjects gave permission to be filmed for research purposes and for their data to be used in the research. Recordings were made using two GoPro cameras mounted on the cabin ceiling at the front and rear of the aircraft, facing the 30 seats. After each boarding, the subjects completed a questionnaire relating to the speed of the process and their personal experience. The responses involved a choice of one from five emotions (a five-point scale) that best described their experience. The Wilcoxon test was used to calculate significant differences ($p < 0.05$). A within-subject design was used, as there was a pair of repeated measurements for each subject (values for both the traditional and new ways of boarding).

Figure. 2. An example of a number indicating where the hand luggage should be stowed. In this case, two pieces should be stowed on top of one another.

Table 4

Boarding time for 30 passengers in seconds. 'Random 1' = random boarding for the first time. 'Random 2' = random boarding for the second time. 'Assigned' = means the location of the hand luggage was assigned within the overhead lockers.

	Random 1	Assigned 1	Random 2	Assigned 2
Time (seconds)	421	333	256	286

Results

The boarding time results are shown in Table 4. Taking all measurements into account, boarding with assigned hand luggage position resulted in the fastest time (a difference of 29 seconds). The second time random boarding seems fasted. However, this is not a fair comparison as in this case not all hand luggage was placed in the overhead lockers. A few hand luggage items that did not fit were given to the flight attendant, which in a real-life setting would cause a delay. It is also possible that there was a learning effect in boarding, as the Assigned process was about 50 seconds faster the second time around.

Regarding the experienced effects, assigned was preferred. The Wilcoxon test showed that speed was significantly different between Random and Assigned (Z-value = -3.9844; $p < 0.001$), with assigned experienced as faster. Assigned was

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also associated with a significantly more positive experience (*Z*-value = -4.1286; $p < 0.001$). Figure 3 shows the passenger experience of the two boarding principles.

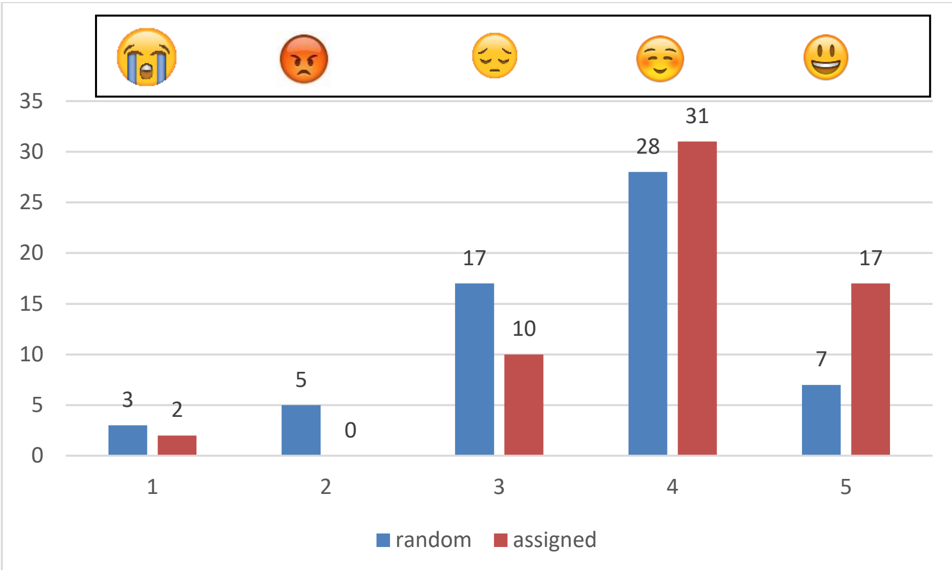

Figure 3. Emotions after each trial for the two boarding principles

Discussion

A good pilot test should include around 150 participants to simulate a real flight, preferably with several groups. The initial random boarding time of the 30 participants was relatively long. For a full airplane with 150 passengers, this would equate to a random boarding time of 35 minutes. The second time was closer to real-life expectations (21 minutes for 150 passengers). Similar research by Briel et al. (2005) reported boarding times of between 16 and 23 minutes, and Steiner and Philipp (2009) reported a boarding time of 23 minutes for 160 passengers. Nevertheless, conditions in the pilot test were similar, aside for the assigning of overhead lockers' positions, which could account for the 29-second difference. This 29 seconds is on the safe side as 2nd time random boarding not all luggage was stowed in the overhead lockers. For a full airplane of 150 passengers, this difference would be 2.5 minutes – a figure comparable to that reported by Steiner and Philipp (2009), who state that a two to four minute reduction in boarding times could be achieved by this means. This reduction is in line with the passenger experience that assigned overhead lockers are faster, with an improved overall experience. However, as stated previously, further research with a larger test group and with real hand luggage is needed to confirm these results.

Discussion

All three studies indicated that luggage storage is one of the leading elements influencing passenger experience and boarding times. In the literature study, seven papers mentioned hand luggage as a significant factor in reducing boarding time. Our observations also showed that aisle blocking is frequently due to luggage storage. Increasing the space between rows (Muir et al., 1996) or providing more space in the overhead lockers (Kierzkowski and Kisiel, 2017) would improve boarding times. However, airlines prefer to have as many passengers as possible on board, making such increases unfeasible. The new method of organizing hand luggage in the pilot test was experienced positively, and there were indications that it could also be 2.5 minutes faster for 150 passengers, which is comparable to the two to four minutes reported by Steiner & Philips (2009). It is thus essential to have the luggage stowing modeled for simulations, as demonstrated by Kierzkowski and Kisiel (2017). For instance, the speed of placing the luggage in the overhead locker is dependent on both how it is stowed and the experience of the traveler. Tang et al. (2012) make a distinction between fast luggage-stowing passengers and slow luggage-stowing passengers.

Training/preparation has a positive effect on boarding times – something that is usually not modeled in simulations. Over the course of several weeks, frequent flyers are likely to board faster. In reality, however, there will often be a mixture of frequent and inexperienced passengers, the combined effect of which is unknown. Age also plays a part. While the effect of age has not been studied for luggage stowage, Lijmbach et al. (2014) have shown that older passengers take approximately two seconds longer, on average, to seat themselves in the middle seat compared with young passengers.

Further research is also needed to establish the precise effects of other promising interventions. The reverse pyramid method or Steffen method (Qiang et al., 2014) may be able to reduce boarding times. This method has been tested in practice, to positive effect (Vincent, 2016). However, its implementation appears complex, with preparation for consuming too much of the crew's time and attention. This problem may also extend to assigned hand luggage. The proposed boarding preparation and crew training hence require exploration and testing in real-life scenarios.

The statement that smarter ways of luggage stowage can increase boarding speeds is supported by the literature review, the observations, and the pilot study reported in this paper, but further study is needed to check the effects and get it implemented in reality.

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