Time flies: Comparing completion times of 3 plane disembarking strategies

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December 15, 2023

1. Executive Summary

While much research comparing the completion times of various boarding methods has taken place, only one published model could be found comparing completion times of disembarking methods. Our goal is to verify their results, as well as to analyze the effect of varying levels of noncompliance to prescribed methods on disembarking completion times. Using a discrete simulation of passengers' movements written in python, we compared 3 disembarking call-off methods: random / no method, by seat letter starting with the aisle seats and ending with the window seats, and by row number starting with the row nearest to the exit, and ending with furthest row. For each combination of call-of method, compliance level (0, 0.25, 0.5, 0.9, 1), and average number of carry-ons per passenger (0, 0.25, 0.5, 0.75, and 1), a trial consisting 50 sample simulations was run, and their results compared. We found the ascending row method to be the most time-consuming; the random and seat methods had very similar times, with the seat method slightly in the lead above carry-on levels of 0.5, but very slightly behind when there were no carry-ons. Further research is needed to determine 1) whether more rows causes the ascending row method to perform worse compared to the other methods, and 2) how long carry-on pick-up times take in the real world and to what extent they are increased by other passengers.

2. Introduction

In the airline industry, having things be time-efficient and reliably on time is very important. For example, delays or cancellations in flight schedules can be potentially very disruptive for the passengers and crew, as it is sometimes very important to be at a destination by a certain time. Avoiding delays and cancellations is also of high interest to airline companies, who typically have contracts that provide passengers full refunds in the case of flight cancellations [1], and are also interested in avoiding a bad reputation.

One source of time consumption, risk of unexpected time loss, and therefore delays, is the turnaround time of an airplane. This refers to the length of time between the arrival and parking of an airplane at the gate or remote apron position, and its next departure. There are multiple time-consuming steps that are taken between arrival and departure, including but not limited to: letting the passengers disembark the airplane; refueling, cleaning, and inspecting the airplane; and letting the next passengers board the airplane [2]. Steffen and Hotchkiss [3] estimate that a 1-minute reduction in turnaround time could save $16,000,000 per year for an airline with 1,500 flights per day.

Two major components of turnaround time are the boarding and disembarking of an airplane. Landeghem and Beuselinck [4] found, from interviews with airport officials, that disembarking takes approximately 10–15 minutes, while boarding is allotted 10 minutes - but is in practice usually exceeded, often up to 30 minutes. Of course, these times do not represent all airports, may have changed over the years, and can of course vary based on factors such as the size and occupancy of the airplane. But, these times give us an idea of how long these processes take in the real world, and how much time (and therefore money) could be saved.

There is already much literature analyzing the effect of different boarding methods on completion times of the boarding process. For example, Landeghem and Beuselinck [4] modelled a large variety of boarding methods onto a cabin with 23 rows and 6 seats per row. The 2 fastest methods performed very similarly. The first method was to descend by row and then letter (23A to 1A, 23B to 1B, 23C to 1C, 23D to 1D, 23E to 1E, then 23F to 1F). The second method involved descending the row, while alternating the seat letter (23A, 22F, 21A, 20F, ..., 23B, 22E, 21B, 20E, ..., 23C, 22D, ..., 23F, 22A, ..., 23E, 22B, ..., 23D, 22C, ...). Another interesting result is that most other methods, including those commonly used by airlines, actually perform considerably worse than letting passengers enter in a random order.

There are also many other published articles analyzing different boarding methods through both simulations [5][6][7] and even real-life experiments [3]. However, published literature comparing different disembarking methods is surprisingly scarce; only one publication was found [8]. Cimler and Olševičová used NetLogo, a programmable modeling environment, to compare 4 disembarking strategies: random, reversed-wilma (aisle seats to window seats), back to front, and front to back. They found that the random and reversed-wilma methods were the least time consuming. The reversed-wilma method usually significantly outperformed the random method - however when no passengers had carry-on luggage, the random method slightly outperformed the reverse-wilma method.

Considering that the disembarking process is similarly time-consuming compared to the boarding process, it seems surprising that the amount of research comparing different disembarking methods is much lower. Therefore, one purpose of our model is to replicate the results of [8]. However, there is one possibly important factor that was not included in [8]: how many passengers actually comply with the prescribed boarding method. It seems likely that, given any disembarking method, there will be at least some passengers in the real world who do not follow it. While the reversed-wilma method may be the fastest when all passengers are compliant, it is not yet clear whether even just a few noncompliant passengers could make the method ineffective. Therefore, in addition to analyzing the effect of the number of passengers with carry-ons, we will also include a compliance parameter that determines what percent of passengers follow the boarding method; sensitivity analysis will also be performed on this parameter.

3. Methods

3.1. **Overview.** The model used was a discrete simulation written in python. To run a simulation, a **`Simulation`** object must be created; the arguments `strat_type`, `compliance` and `avg_carry_ons` must be passed to its constructor.

A **`Simulation`** initializes by creating a list of **`Passenger`** objects, and initializing the attributes of each passenger, which are listed in 3.4. Attributes of a passenger include their location (which starts as a seat; possible locations are described in 3.2), walkspeed, number of carry-ons left to pick up, and whether they are compliant. Walkspeed is randomly generated using constants described in 3.3, while number of carry-ons and compliance is also randomly assigned based on the corresponding arguments to the **`Simulation`**'s constructor. Carry-ons are restricted to being 0 or 1, therefore `avg_carry_ons` is also the probability that a given passenger will have a carry-on. Similarly, `compliance` is the probability that a given passenger will be compliant.

After initialization, the **`Simulation`** can then be run. One way this can be done is by repeatedly calling `Simulation.tick()`, which performs one time-step, or tick, representing 0.05 seconds of real-time. A tick of a simulation consists iterating of through the list of **`Passenger`**s in random order. At each iteration, the current **`Passenger`** is passed as an argument to the `disembarking_strat.update_passenger()` method of the particular **`disembarking_strat`** being used. The second way of running a **`Simulation`** is simply by calling `Simulation.run()`, which calls `tick()` repeatedly until all passengers are finished, and returns the amount of simulated time (in seconds) that it took.

3.2. **Cabin Model.** Figure 1 shows how the cabin was modeled. For the sake of simplicity, all seats are of the same type; there is no first or business class. This choice, as well as the number of seats (6) and rows (32), was based on the IM^{2}C problem that inspired this model [9]. The distance between rows (30 inches), also known as the seat pitch, comes from the specifications of the Boeing 737-800 version 1 [10], a very common passenger airplane. Specifically, the seat pitch of the economy class was used.

There are two types of locations that a passenger can occupy in the simulation: seats, which are represented by strings such as "A2", and intervals on the hallway, which are represented by length-2 lists such as [30, 55]. The hallway is considered to be a number line using units of inches. 0 is considered to be 30 inches before the first row, and higher rows correspond to higher positions. There is only one exit; therefore a passenger is considered finished when they occupy an interval containing 0 or negative numbers.

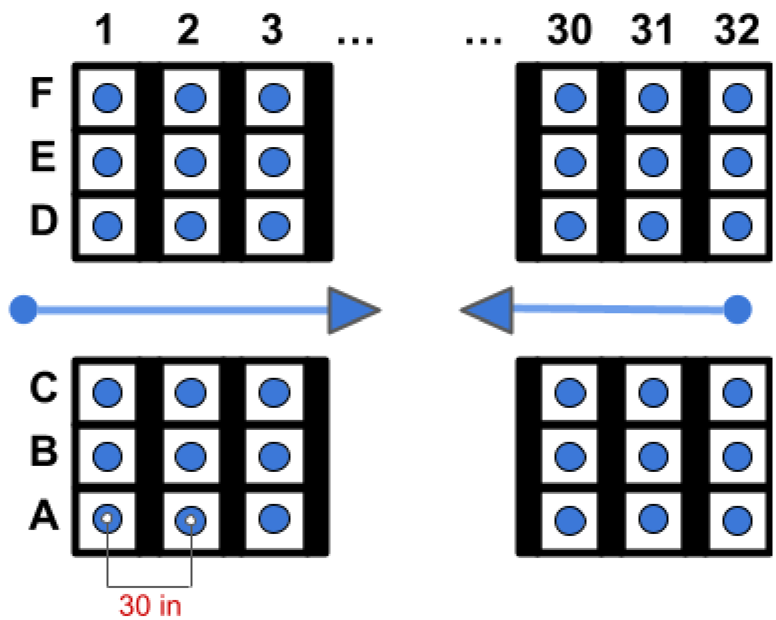

FIGURE 1. Physical model of the cabin being used. There are 32 rows, and 6 seats labelled A-F. There are two types of locations that can be occupied: seats (represented by strings such as "A1"), and intervals on the hallway (represented by length-2 lists such as [30, 55]).

3.3. **Constants.** Many constants were necessary; below is a listing of both their descriptions and the values chosen for them. The reasoning for the choice of `seat_pitch` and `num_rows` has already been described. The choices for the other constants were somewhat more arbitrary, being derived from intuition - for example, stopping simulations at an hour will only significantly affect the time statistics of boarding methods that go over an hour somewhat frequently, in which case its times will be long enough for us to see how bad it is.

constant	value	description
`seat pitch`	30	The width (in inches) of each row. Or, the distance between a point on a seat and the same point on a seat in front or behind it.
`num_rows`	32	Number of rows of seats in the cabin.
`seat_move_time`	3	The amount of time (in seconds) it takes for a passenger to move from a seat to the seat next to them, or from a seat to the hallway.
`hall_interval_size`	25	The diameter (in inches) of the interval that passengers occupy while in the hallway. In other words, how much space someone takes up while standing or walking.
`tick_time`	0.05	How much real world time (in seconds) a tick represents
`carry_on_time`	4	How much time it takes (in seconds) for someone to pick up a carry-on bag from the overhead bins.
`walk_speed_mean`	44	Mean walkspeed (in inches / second) of the normal distribution from which passengers' walkspeeds are randomly generated.
`walk_speed_sd`	18	Standard deviation of the normal distribution from which passengers' walkspeeds are generated.
`walk_speed_min`	10	If a random walkspeed is generated below this value, it will round up to this value. Setting this to a positive value is necessary so that negative or zero walkspeeds do not occur.
`sim_time_max`	60 * 60	Maximum amount of (simulated) time (in seconds) that a simulation will run for.

3.4. **Passenger attributes.** Again, each passenger in a `Simulation` is represented as a `Passenger` object. Here we list the attributes of the `Passenger` class. Some attributes are self-explanatory, yet listing them out will be important for describing the passenger movement mechanics. A passenger's `p_id` is a unique number used as a list index by the **`Simulation`** object. Their `walkspeed` is randomly assigned as described in 3.3, while `carry_ons_left` and `compliant` are initialized as described in 3.1. The other 4 attributes will be described in 3.5.

p_id	location	location_moving_to
state	move_time_remaining	carry_on_time_remaining
walkspeed	carry_ons_left	compliant

3.5. **Passenger movement mechanics.** All passengers begin with `state = "default"` and their `location` set to the seat assigned to them, while `location_moving_to`, `carry_on_time_left`, and `move_time_remaining` are set to `None`. There are 3 types of movement: from seat to seat, from seat to that seat's corresponding hallway interval, or from a hallway interval to a lower hallway interval determined by their walkspeed. If a passenger moves onto a hallway interval containing 0 or negative numbers, their `state` is set to `"finished"`, and `location` set to `None`.

With the random method, a passenger in the default state will always move to the next possible location as long as it is not occupied. In the seat method (also called reversed-wilma method), passengers freely move from seat to seat, but cannot move from seat to hallway until all members of the previous seat group are finished (unless the passenger is not compliant, in which case they move freely). In the row method, compliant passengers cannot move at all until all members of the lower rows are either on the hallway or finished.

Moving from one seat to another, or a seat to a hallway, is considered to take a constant amount of time in seconds, hence the constant `seat_move_time`. If a passenger is currently moving as such, their `state` is set to `"moving"`, and their `move_time_remaining` indicates how many seconds it will take for them to be done. In this state, a passenger's `location` indicates where they are moving from, and their `location_moving_to` indicates where they are moving to. Also, both locations are considered occupied; no passenger can move in a way that intersects either location. Once `move_time_remaining <= 0`, `location` is set to their `location_moving_to`, while `location_moving_to` and `move_time_remaining` are set to `None`. Also, their `state` is set to `"default"`, unless they just moved onto the hallway and have carry-ons, in which case it is set to `"grabbing-carry-on"`, and `carry_on_time_left` is set to `constants.carry_on_time`. In this case, their state will return to `"default"` once `carry_on_time <= 0`.

The third type of movement, from hallway interval to a lower hallway interval, does not require using the mechanics above; their location simply changes to the next hall interval.

3.6. **Trials performed.** As mentioned before, three disembarking strategies were tested: random, by seat letter (C and D, then B and E, then A and F), and by row (in ascending order). The `compliance` values used for the trials were 0, 0.25, 0.5, 0.75, 0.9, and 1, while the values used for `avg_carry_ons` were 0, 0.25, 0.5, 0.75, and 1. A trial was performed for every combination of `strat_type`, `compliance`, and `avg_carry_ons` values. Each trial consisted of 50 sample simulations, and each simulation's completion time was recorded.

4. Results

The practical minimum (5th percentile), average, and practical maximum completion time (95th percentile) of all trials are shown in Figure 2. For the purpose of being able to compare small differences in completion times, any times above 15 minutes were not graphed; however all times can be found in the attached json files. Only the ascending row method produced such times; the other two methods did not get close.

One result we share with [8] is that the ascending row method has significantly longer times regardless of what values the parameters are (except when compliance is 0, in which case all methods behave exactly like the random method). However, the relative increase in time between the row method and the other two methods is significantly higher. For us, with compliance = 1 and average # carry-ons = 1, the row method resulted in an average time 3.2 times higher than the random method and 3.4 times higher than the seat method. In contrast, for them the ratio between the average row method time and average random method time never exceeded 1.3 for any experiment, and between row method and seat method never exceeded 1.8. I suggest that this difference is caused by their model consisting of only 12 rows, as compared to 32 for ours. While our choice of other constants (such as seat pitch) likely differs slightly, I do not believe such slight differences would result in such large increases in the row method completion time.

Another result we share with [8] is that as the average number of carry-ons increases, the seat method becomes better in comparison to the random method. However, we found the improvement to be small, which differs from their results, where the random method took 20-80% longer than the seat method, except for two trials. One such trial was when luggage manipulation time (which we did not include as a parameter) was 1 second; the other was when no passengers had luggage to remove. This difference may also be caused by our model having a higher number of rows. However, I believe much of this difference is caused by a difference in how we approached the constants and parameters relating to luggage. They had 3 such parameters: % passengers with luggage, luggage manipulation time, and luggage delay (which causes picking up luggage to be slower the more that other passengers are also picking up luggage). Also, each of their experiments consisted of holding 2 parameters constant, and varying the other. The respective values of the parameters when held constant were 90%, 6 seconds, and 0.3. Not only did our experiment not have a luggage delay parameter (which would have likely made the seat method better, considering that higher average # carry-ons did), our luggage manipulation time (`carry_on_time`) was a constant, and was set to 4 seconds (if it was higher like theirs, it would have also likely made the seat method better).

Another result that can be seen from these trials is how the compliance level affects the seat and row methods. Perhaps unsurprisingly, as the compliance level decreases, the completion times tend to get closer to the completion times of the random method. This is a gradual process; a compliance level of 0.9 yields very similar results to a compliance level of 1. However, when the compliance level is 0.25, the seat method performs worse than at both 0 compliance and 0.5-1 compliance. Intuitively, this makes some sense: if only a quarter of passengers comply with the method, it is essentially the same as the random method, except that some passengers choose not to move even when there is space to do so. This would make it especially slow when a passenger in a middle seat chooses not to move, since they would block the window seat passengers from moving. Also, it would take significantly longer for the aisle seat group to fully finish (and therefore for compliant middle-seat passengers to start moving), since there are other seat groups in the hallway when the aisle seat passengers disembark.

Regardless of differences between our models, certain results are clear. One is that the ascending row method of disembarking always takes longer than the random and seat method. Another is that the more time is taken from picking up luggage, the better the seat method performs. A third is that small amounts of noncompliance do not significantly affect completion times of any of the 3 methods.

5. Discussion

Again, there are two main purposes of this project: one is to verify the results of [8], and the other is to analyze the effect of varying levels of passenger compliance with the prescribed boarding method.

With regards to the first purpose, certain results were the same: we both found the ascending row method to be significantly slower than the random and seat method, and we also both found the seat method to improve as the percentage of passengers with carry-ons increased. However, our model resulted in significantly worse performance for the ascending row method, which may have been caused by our model having a higher number of rows. Also, our model only resulted in small relative differences between the random and seat method, while the seat method in their model almost always performed significantly better than the random method. This difference is likely partly caused by the difference in parameters and constants relating to luggage pick up time, however the number of rows may also be a factor.

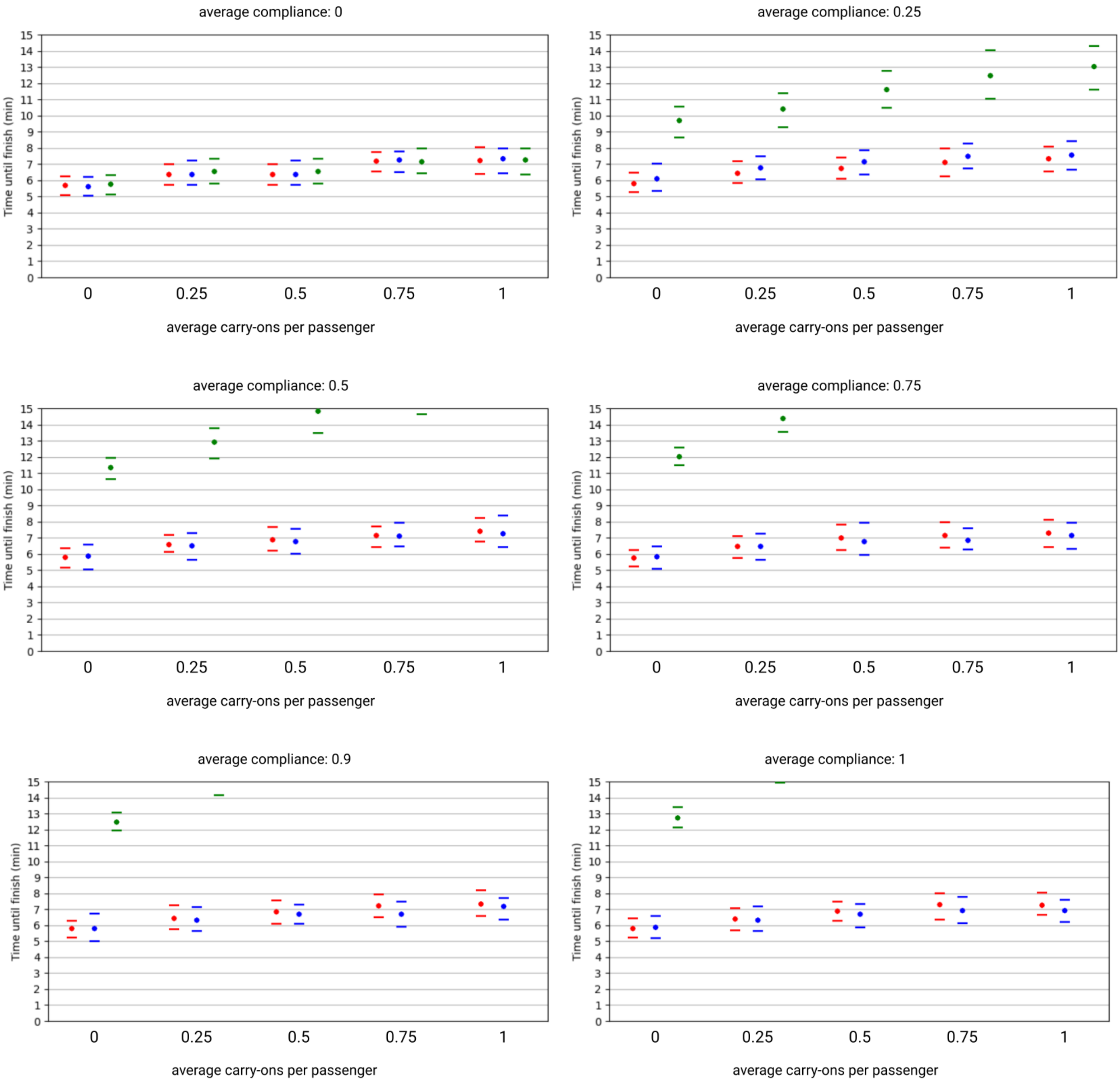

Figure 2. Effect of disembarking strategy, compliance level, average carry-ons on completion time. Random method is in red and on the left, seat method (or reversed-wilma method) is in blue and in middle, ascending row method is in green and on the right. Each method's 5th percentile, average, and 95th percentile completion times are shown on the graphs.

With regards to the second purpose, the overall trend is that as the compliance level of a particular method goes down, the completion times gradually get closer to that of the random method. Small levels of noncompliance such as 0.9 (and to some extent, 0.75) do not significantly change the completion times of any method. However, the exception to this is that at a compliance of 0.25, the seat method is slower than it is at both lower and higher levels of compliance. However, such low compliance levels are probably unlikely; therefore the overall trend can probably be assumed in practice when making decisions of what disembarking method to use.

All the results that have been stated can be seen by looking at multiple different trials. For example, the result that the seat method performs worse at a compliance of 0.25 can be seen for all values of the average-carry-ons parameter; for all 5 average-carry-on values, the seat method at a compliance of 0.25 gives the maximum 5th percentile, average, and 95th percentile completion times out of all the other compliance levels - with the singular exception (out of 75 possible exceptions) of the 0.75-compliance and 0.5-carry-on trial, which yields a slightly higher 95th percentile than the corresponding 0.25-compliance, 0.5-carry-on trial. Similar replications can be seen for all other results; therefore I believe that the results can be stated with high confidence.

There are several limitations to this experiment that lead to some uncertainties which have been previously stated. One is that the number of rows (32) was constant. While I believe that some of the differences between our model's results and [8] are due to difference in number of rows, this remains a speculation that should be investigated further. This could potentially have implications for deciding which method to use. For example, perhaps there are other factors that drive an airline towards choosing the ascending row method, such as to reduce risk of infection between passengers (in fact, boarding by row has been found to have this effect [11], and disembarking by row may have a similar effect). In this case, it would be important to have a clear idea of how long this method will take, and relying on small-row models may give the impression that it will take less time than it actually does. Therefore one avenue of future research should be to vary the number of rows and analyze the effect on completion time of different disembarking times.

Another limitation of this experiment is that only one parameter relating to luggage pick-up times (`avg_carry_ons`) was varied. As previously stated, this may have caused some of the difference in results between our model and [8]. In regards to this limitation, introducing and analyzing the parameters they did to our model may also be a future avenue of research, however it is unclear whether the parameters they chose, and the values they chose for them when held constant, actually reflect real-world conditions. And the choice of the constant `carry_on_time` for my model was admittedly somewhat arbitrary.

Therefore, perhaps another avenue of future research would be to take real-world measurements of how long it takes people to pick up luggage, and to what extent other people make their pickup times longer. Considering that the difference in luggage-related constants and parameters between our model and [8] may have caused the seat method to perform so much better in their model compared to in ours, conducting this research may be important.

6. Conclusion

There are three main results that can be concluded from both this experiment and [8]. One is that the ascending row method of disembarking consistently takes significantly longer than the random method and the seat method, though further research into the effect of row number on completion times of the ascending row method is needed for a full understanding. The second result is that as the amount of time that passengers are picking up luggage from the overhead bins increases, the more the seat method becomes better in comparison to random disembarking; although research into how much time is actually spent removing luggage is needed to determine which method is faster in the real world. Finally, small levels of noncompliance to the prescribed disembarking method among passengers, such as 10%, do not significantly change completion times of either the random, seat, or ascending row method.

In addition to the constants and parameters related to luggage removal time, other information such as the distribution of passengers' walk speeds, distance kept from other passengers, and amount of time to move between seats should also be researched in the real world if a truly accurate model is desired, since these constants were assigned somewhat arbitrarily. Also, comparison between disembarking completion times of the models and of the real world could take place to further identify weak points in the models.

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