Boarding airline passengers in order of reserved overhead bin space

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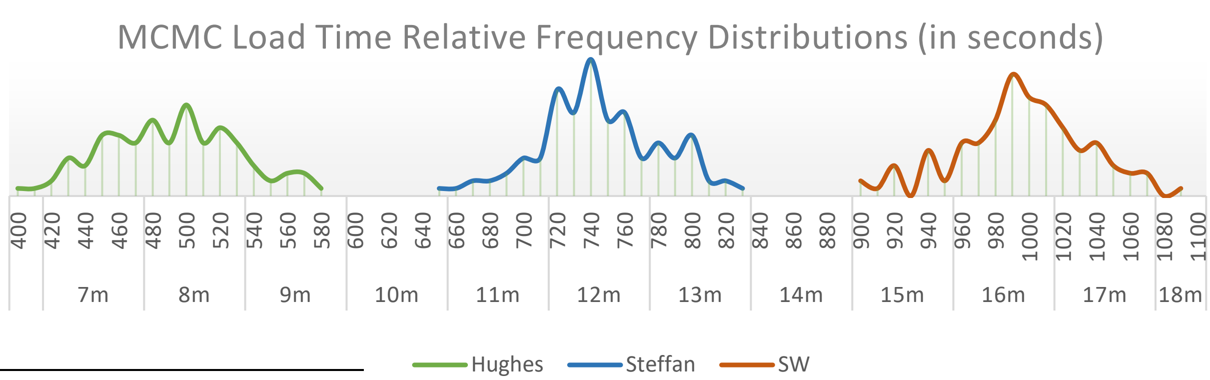
Airlines flying 737s, can save up to 50% on boarding time
(an average of 8 minutes per boarding cycle valued at ~$750M/year[i])
while creating a new revenue stream, sparking national attention, and improving customer experience.

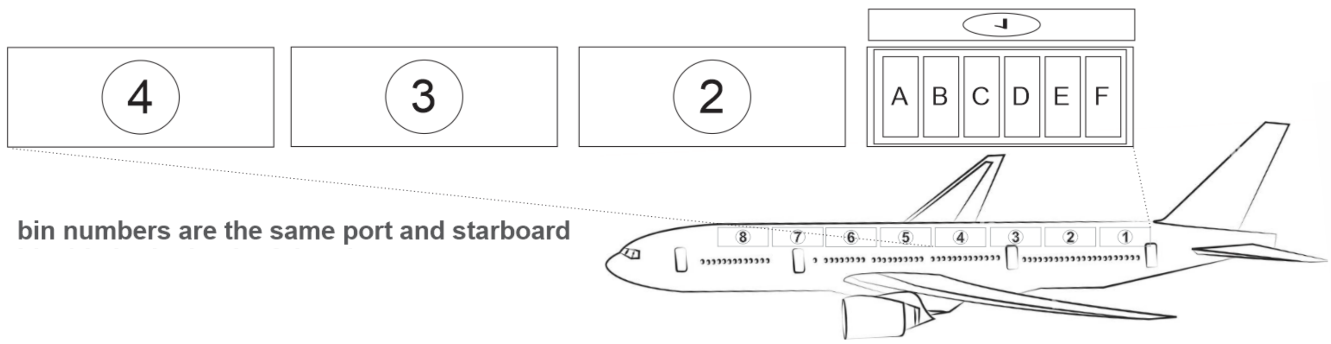
Abstract

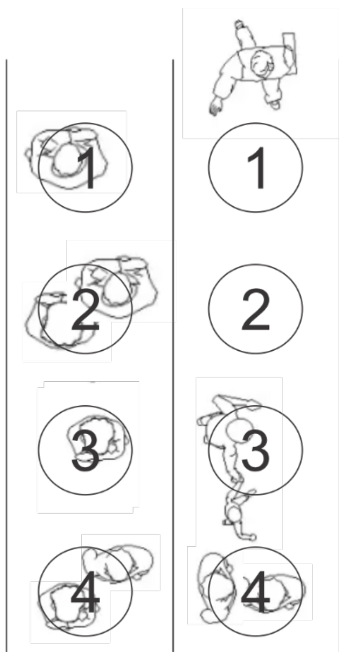
Numerous studies have concluded[ii], the most effective strategy for reducing overall boarding time (the most time-consuming portion of aircraft turnaround) is to minimize the bottlenecks that occur when passengers block the aisle while stowing their carry-on luggage in the overhead bins. In the novel methodology described in this document, (Hughes) addresses the problem directly by having passengers board with their families in order of their reserved overhead bin locations on the plane, with those assigned to overhead bins at the rear of the plane boarding first within each boarding group. Only one family[1] accesses a pair of parallel overhead bins per boarding group. This method allows multiple passengers to simultaneously place their carry-on luggage in the overhead bins at the same time and dramatically reduces bottlenecks during boarding.

No existing public research has directly addressed this issue in the manner outlined here. Previous publicly available investigations[iii] demonstrating time savings from tangentially related methodologies, have primarily focused on alternative boarding methodologies[2] that are impractical outside a laboratory environment. Using a Markov Chain Monte Carlo (MCMC) algorithm, the Hughes methodology demonstrates the potential for a signification reduction (averaging 50%) in loading time compared to currently implemented models at commercial airlines, and a significant improvement over what was previously assumed to be the '[optimal][iv]' methodology for fast civilian commercial airplane boarding given practical[v] limitations.



[1] 'family' is used in place of the phrase 'group of passengers with the same reservation confirmation number' for brevity and to avoid naming collision / verbal confusion with the term 'boarding group.'
[2] '(Steffan)' or '(Steffan 2008a)' refers to the methodology proposed by Jason H. Steffan in 2008 (see appendix)





Overhead bins on the aircraft will be labeled from the aft forward (back to front), where bins labeled #1 are at the stern (far back). Bins opposite each other on the isle will have the same bin number. Passengers can use either aft or starboard (left or right) bins to which they have been assigned.

Passengers line up with their boarding group on a sticker on the floor[vi] at the gate that corresponds to their assigned overhead bin number before boarding[vii].

The boarding group assigned to a passenger travelling alone is the same as the their assigned luggage slot in their overhead bin. All family members use the same bin and are assigned to the boarding group with the family member that has the lowest slot number. This has the side-effect of moving large groups up in the boarding process, which helps reduce their seating time (and other passenger's reseating time)[viii]. Families traveling with infants or large parties can be assigned to lower numbered bins[ix].

The highest overhead bin number in the earliest boarding group will be the most desirable on an aircraft (A12 is more valuable than F1).

Airlines can save money, turn overhead bin space into a profitable asset and <u>keep their existing (open or assigned) seating policy</u>.

Gate Positions

Left Gate Lane	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	A
Right Gate Lane	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	B

1A	2A	3A	4A	5A	6A	7A	8A	9A	10A	11A	12A	13A	14A	15A	16A	17A	18A	19A	20A	21A	22A	23A	24A
1B	2B	3B	4B	5B	6B	7B	8B	9B	10B	11B	12B	13B	14B	15B	16B	17B	18B	19B	20B	21B	22B	23B	24B
1C	2C	3C	4C	5C	6C	7C	8C	9C	10C	11C	12C	13C	14C	15C	16C	17C	18C	19C	20C	21C	22C	23C	24C

12	11	10	9	8	7	6	5	4	3	2	1

Cabin Diagram

12	11	10	9	8	7	6	5	4	3	2	1

1D	2D	3D	4D	5D	6D	7D	8D	9D	10D	11D	12D	13D	14D	15D	16D	17D	18D	19D	20D	21D	22D	23D	24D
1E	2E	3E	4E	5E	6E	7E	8E	9E	10E	11E	12E	13E	14E	15E	16E	17E	18E	19E	20E	21E	22E	23E	24E
1F	2F	3F	4F	5F	6F	7F	8F	9F	10F	11F	12F	13F	14F	15F	16F	17F	18F	19F	20F	21F	22F	23F	24F

In the Hughes methodology, bottlenecks are reduced as much as practically possible.

Savings and Efficiency Gains

The proposed boarding optimization methodology offers several key benefits that can drive significant value for airlines:

1. **Reduced Costs**: Faster turnaround times and a more efficient boarding process can lead to substantial cost savings for airlines. By minimizing the time planes spend on the tarmac, airlines can reduce fuel consumption and operational expenses.
2. **Increased Revenue**: By turning overhead bin space into a profitable asset, airlines can generate additional revenue streams. This can be achieved by allowing passengers to purchase or use loyalty points to secure specific overhead bin space.
3. **Enhanced Customer Experience**: A smoother, more streamlined boarding process can greatly improve passenger satisfaction and reduce travel friction. This can translate into increased customer loyalty and repeat business.
4. **Reduced Stress on Employees**: A well-designed boarding system can alleviate the burden on airline staff, leading to improved morale, reduced turnover, and better customer service.

Newsworthiness and Industry Impact

The timing for this boarding optimization approach is ripe, as the industry is actively seeking solutions to improve the passenger experience and address ongoing challenges:

1. **Industry Recognition**: The recent comments by the CEO of Southwest about changes to the boarding process underscore a widespread recognition of the inefficiencies in the current system. This creates an opportunity for the adopting airline to position itself as an industry leader.
2. **Media Attention**: The novelty of this approach to optimize boarding will garner significant interest[x] not only from industry insiders but also from the general public[xi].
3. **Positive News Story**: With increasing media focus on the travel industry's recovery post-pandemic and ongoing challenges such as delays and customer service issues, a successful implementation of this new boarding process could serve as a positive news story, showcasing innovation and proactive steps by airlines to improve the passenger experience.

In summary, the practical implementation of this boarding optimization method presents significant opportunities for efficiency gains, revenue generation, and enhanced customer satisfaction. If executed well, it could not only revolutionize airline boarding procedures but also position the adopting airline as a leader in innovation within the industry.

By combining data-driven analysis, advanced simulation techniques, and iterative testing, this comprehensive approach ensures that the final boarding optimization solution is both scientifically validated and practically implementable, delivering tangible benefits to airlines, their employees, and their passengers.

The following demonstrates an example in practice…

Visual Demo [ALPHA]: https://202405boardbyoverheadbinv3.netlify.app [xii] The visualization, in its alpha state and a WIP at the time of this writing, does not accurately reflect the math with regard to the portion of the animation of the passengers moving from putting their lugging in overhead bins to their seats. The MATH is right, the UI is wrong. Due to the volume of objects, the browser gets behind keeping track of everything. But hopefully the demo is far enough along to get the general point across. The final state and timing are eventually correct.

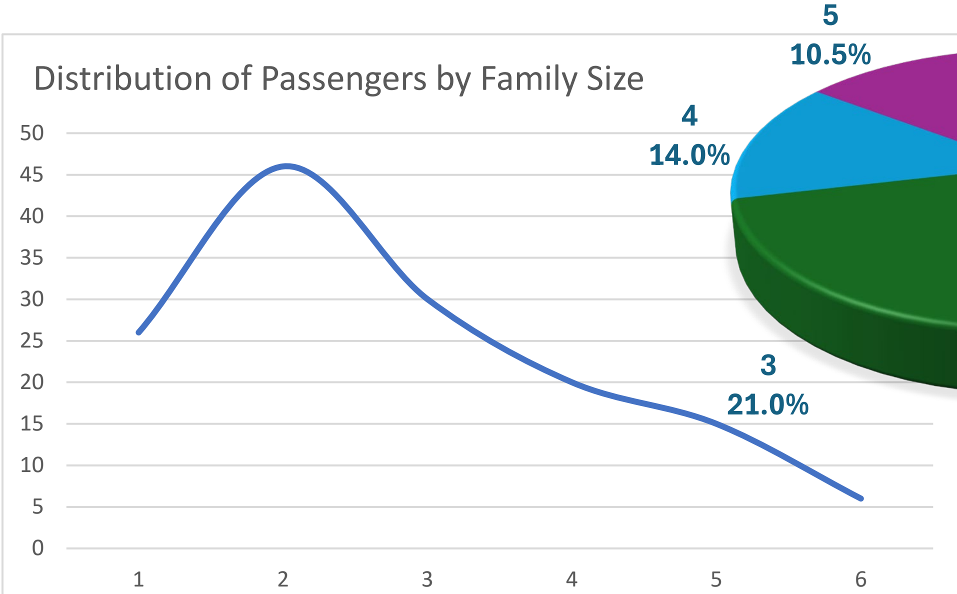
Boarding Groups

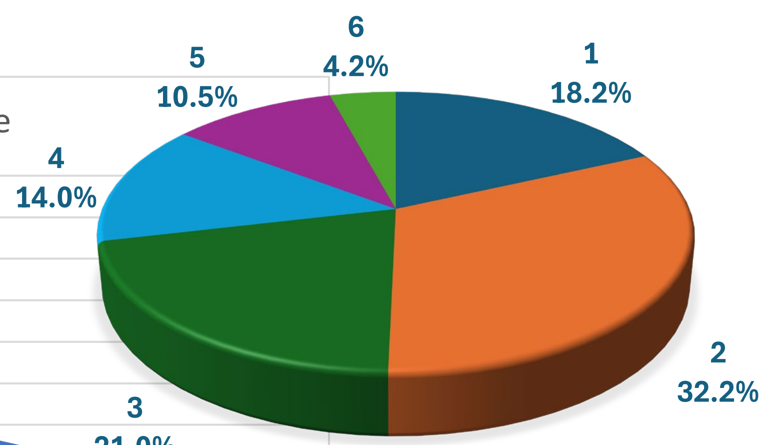
The total number of boarding groups is determined by the sizes of the families[3] for the flight[xiii]. In the MCMC simulations, the distribution of family sizes is an oscillating variable, but the following data are a reasonable representation of an average considered for the model, which would result in 7 boarding groups, labeled for passengers as A,B,C,D,E,F,&G but represented as numbers in the tables below[xiv].

For the purposes of the models, we're assuming 143 booked passengers for a flight on a 737-300 with 144 seats[xv] (24 rows x 2 sets of 3 seats) with 24 overhead bins[xvi] (12 on each side of the isle) *see diagram above*.

Group Size	Quantity of Groups	Passengers in Groups	Percent of Total Passengers
1	26	26	18.2%
2	23	46	32.2%
3	10	30	21.0%
4	5	20	14.0%
5	3	15	10.5%
6	1	6	4.2%
		143	**Total**

Bin #		
No Carry Ons	7	
1	10	bags per overhead bin pair
2	10	
3	10	
4	10	
5	12	
6	12	
7	12	
8	12	
9	12	
10	12	
11	12	
12	12	
	143	**Total**





[3] Of course, if every family size equals 1, the differences between the Hughes and Steffan 2008a models are less dramatic.

Boarding Group | Order	PassengerID	FamilyID	GroupSize	BinID	Slot	HasCarryOn
01-01	22	22	1	0	0	FALSE
01-02	23	23	1	0	0	FALSE
01-03	24	24	1	0	0	FALSE
01-04	25	25	1	0	0	FALSE
01-05	26	26	1	0	0	FALSE
01-07	71	49	2	0	0	FALSE
	72	49	2	0	0	FALSE
01-08	119	64	4	8	2	TRUE
	120	64	4	8	3	TRUE
	121	64	4	8	4	TRUE
	122	64	4	8	5	TRUE
01-09	111	62	4	9	2	TRUE
	112	62	4	9	3	TRUE
	113	62	4	9	4	TRUE
	114	62	4	9	5	TRUE
01-10	103	60	4	10	2	TRUE
	104	60	4	10	3	TRUE
	105	60	4	10	4	TRUE
	106	60	4	10	5	TRUE
01-11	128	66	5	11	2	TRUE
	129	66	5	11	3	TRUE
	130	66	5	11	4	TRUE
	131	66	5	11	5	TRUE
	132	66	5	11	6	TRUE
01-12	138	68	6	12	2	TRUE
	139	68	6	12	3	TRUE
	140	68	6	12	4	TRUE
	141	68	6	12	5	TRUE
	142	68	6	12	6	TRUE
	143	68	6	12	7	TRUE

All passengers after the first 7 have a carry-on bag.

Boarding Group | Order	PassengerID	FamilyID	GroupSize	BinID	Slot	HasCarryOn
02-01	61	44	2	1	2	TRUE
	62	44	2	1	3	TRUE
02-02	51	39	2	2	2	TRUE
	52	39	2	2	3	TRUE
02-03	41	34	2	3	2	TRUE
	42	34	2	3	3	TRUE
02-04	31	29	2	4	2	TRUE
	32	29	2	4	3	TRUE
02-05	97	58	3	5	2	TRUE
	98	58	3	5	3	TRUE
	99	58	3	5	4	TRUE
02-06	88	55	3	6	2	TRUE
	89	55	3	6	3	TRUE
	90	55	3	6	4	TRUE
02-07	79	52	3	7	2	TRUE
	80	52	3	7	3	TRUE
	81	52	3	7	4	TRUE
02-08	73	50	3	8	6	TRUE
	74	50	3	8	7	TRUE
	75	50	3	8	8	TRUE
02-09	115	63	4	9	6	TRUE
	116	63	4	9	7	TRUE
	117	63	4	9	8	TRUE
	118	63	4	9	9	TRUE
02-10	107	61	4	10	6	TRUE
	108	61	4	10	7	TRUE
	109	61	4	10	8	TRUE
	110	61	4	10	9	TRUE
02-11	133	67	5	11	7	TRUE
	134	67	5	11	8	TRUE
	135	67	5	11	9	TRUE
	136	67	5	11	10	TRUE
	137	67	5	11	11	TRUE
02-12	123	65	5	12	8	TRUE
	124	65	5	12	9	TRUE
	125	65	5	12	10	TRUE
	126	65	5	12	11	TRUE
	127	65	5	12	12	TRUE

Boarding Group | Order	PassengerID	FamilyID	GroupSize	BinID	Slot
03-01	63	45	2	1	4
	64	45	2	1	5
03-02	53	40	2	2	4
	54	40	2	2	5
03-03	43	35	2	3	4
	44	35	2	3	5
03-04	33	30	2	4	4
	34	30	2	4	5
03-05	100	59	3	5	5
	101	59	3	5	6
	102	59	3	5	7
03-06	91	56	3	6	5
	92	56	3	6	6
	93	56	3	6	7
03-07	82	53	3	7	5
	83	53	3	7	6
	84	53	3	7	7
03-08	76	51	3	8	9
	77	51	3	8	10
	78	51	3	8	11
03-09	8	8	1	9	8
03-10	4	4	1	10	8
03-11	2	2	1	11	10
03-12	1	1	1	12	11

Boarding Group | Order	PassengerID	FamilyID	GroupSize	BinID	Slot
04-01	65	46	2	1	6
	66	46	2	1	7
04-02	55	41	2	2	6
	56	41	2	2	7
04-03	45	36	2	3	6
	46	36	2	3	7
04-04	35	31	2	4	6
	36	31	2	4	7
04-05	27	27	2	5	8
	28	27	2	5	9
04-06	94	57	3	6	8
	95	57	3	6	9
	96	57	3	6	10
04-07	85	54	3	7	8
	86	54	3	7	9
	87	54	3	7	10
04-08	12	12	1	8	10
04-09	9	9	1	9	9
04-10	5	5	1	10	9
04-11	3	3	1	11	11

Boarding Group | Order	PassengerID	FamilyID	GroupSize	BinID	Slot
05-01	67	47	2	1	8
	68	47	2	1	9
05-02	57	42	2	2	8
	58	42	2	2	9
05-03	47	37	2	3	8
	48	37	2	3	9
05-04	37	32	2	4	8
	38	32	2	4	9
05-05	20	20	1	5	10
05-06	17	17	1	6	9
05-07	14	14	1	7	9
05-08	13	13	1	8	11
05-09	10	10	1	9	10
05-10	6	6	1	10	10

Boarding Group | Order	PassengerID	FamilyID	GroupSize	BinID	Slot
06-01	69	48	2	1	10
	70	48	2	1	11
06-02	59	43	2	2	10
	60	43	2	2	11
06-03	49	38	2	3	10
	50	38	2	3	11
06-04	39	33	2	4	10
	40	33	2	4	11
06-05	29	28	2	5	10
	30	28	2	5	11
06-06	18	18	1	6	10
06-07	15	15	1	7	10
06-09	11	11	1	9	11
06-10	7	7	1	10	11
07-05	21	21	1	5	11
07-06	19	19	1	6	11
07-07	16	16	1	7	11

Passenger 65's ticket would read "D1" for boarding group (and order), minimal changes to ticket templates and internal system would be required to implement this methodology. However, passengers would be notifying the airline of carry-on baggage and possibly selecting overhead bins during the reservation process, and/or at arrival at the airport, hopefully right alongside the similar pages for checked baggage.

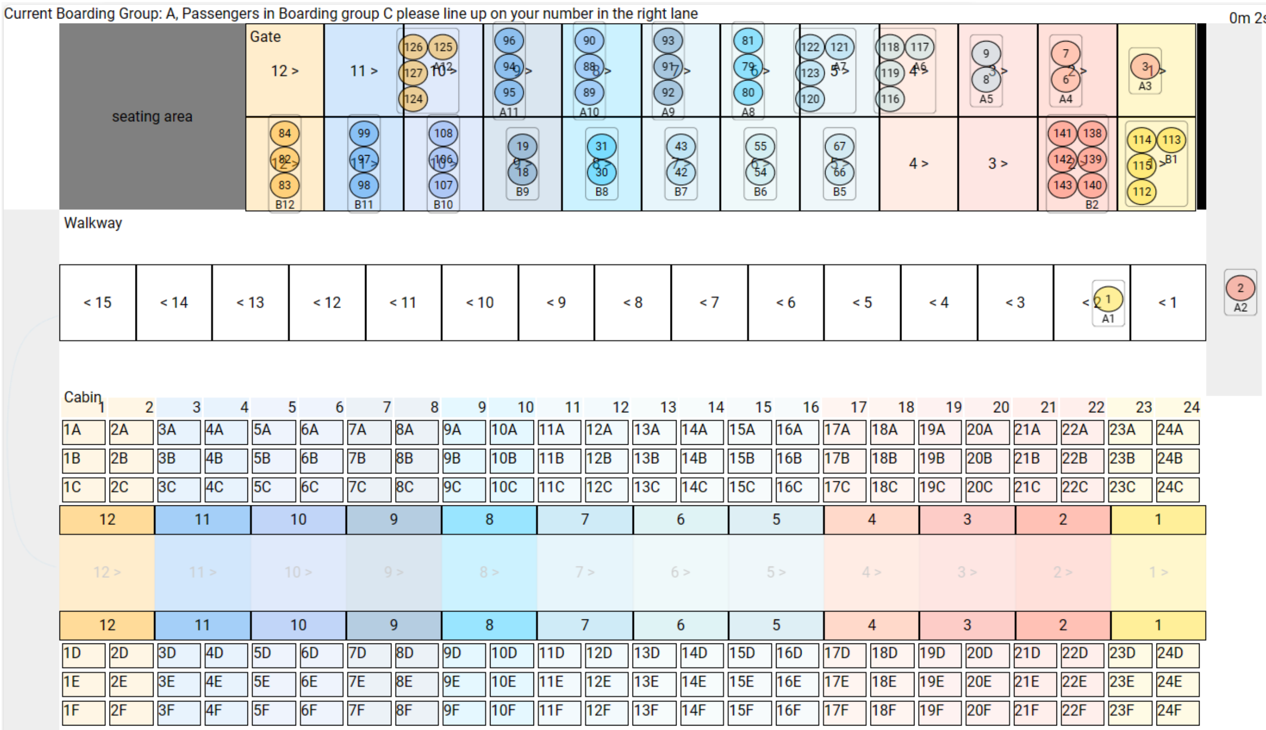
The largest boarding group in this example is 38 passengers. The smallest is 14. The max boarding group size allowed in the model is 40, the minimum is 1. 144 passengers / 7 boarding groups = ~20.5 per boarding group. It would be trivial to move the passengers from 2-12 (B12) to 3-12 (C12), and 3-12 (C12) to 4-12 (D12), which is empty / or push any other families back a boarding group to even out the boarding group sizes if a max number is reached.

The fixed max family size is 6, if that number is increased, spacing between families may be necessary. The max family size is the max capacity of 2 overhead bins.

Depending on the valuation of the optimization algorithm, not all bins would be available for reservation. Only bins with ample slots for the entire family would be available for reservation.

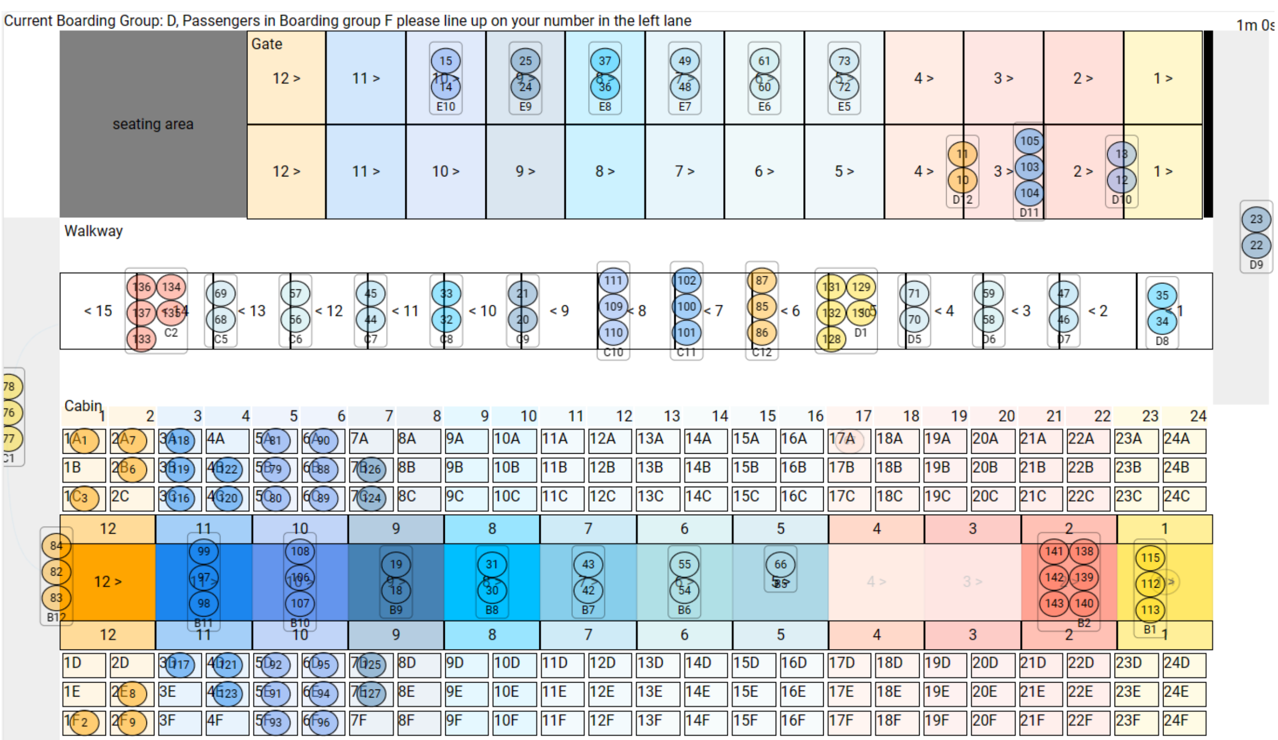
The following visualization does not use the precise data above, but the next iteration of the model with the fastest total time / cleanest boarding. The primary difference from the data on this page is that in this simulation, passengers who handle luggage are more likely to occupy seats closer to the isles than the rest of their family.

2 seconds into the boarding process. There are no bottlenecks. Shown for comparison to below image.

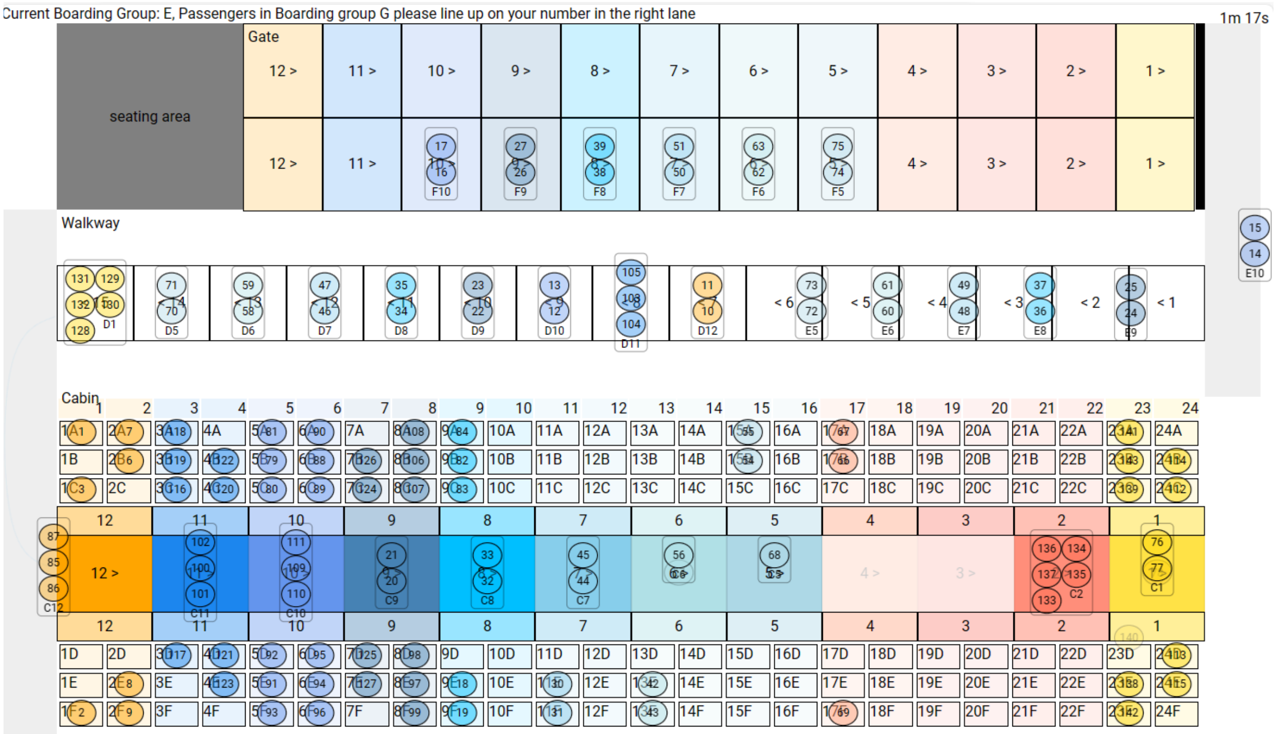


Bottlenecks are highlighted by the darker colors.

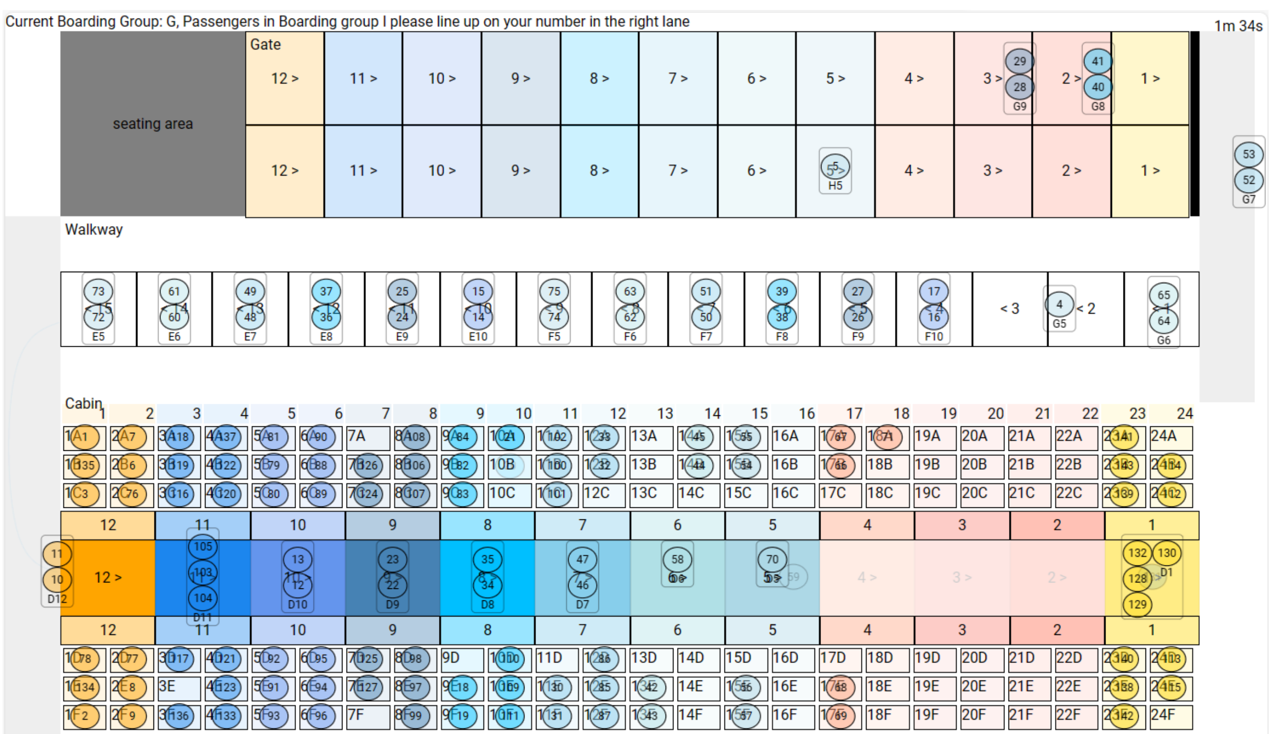
1 minute into the boarding process, the first parallel bottleneck occurs as the passengers from Boarding Group B simultaneously reach their overhead bins. There are fewer chances for bottlenecks with Boarding Group A as it consists of more families without carry-on luggage.



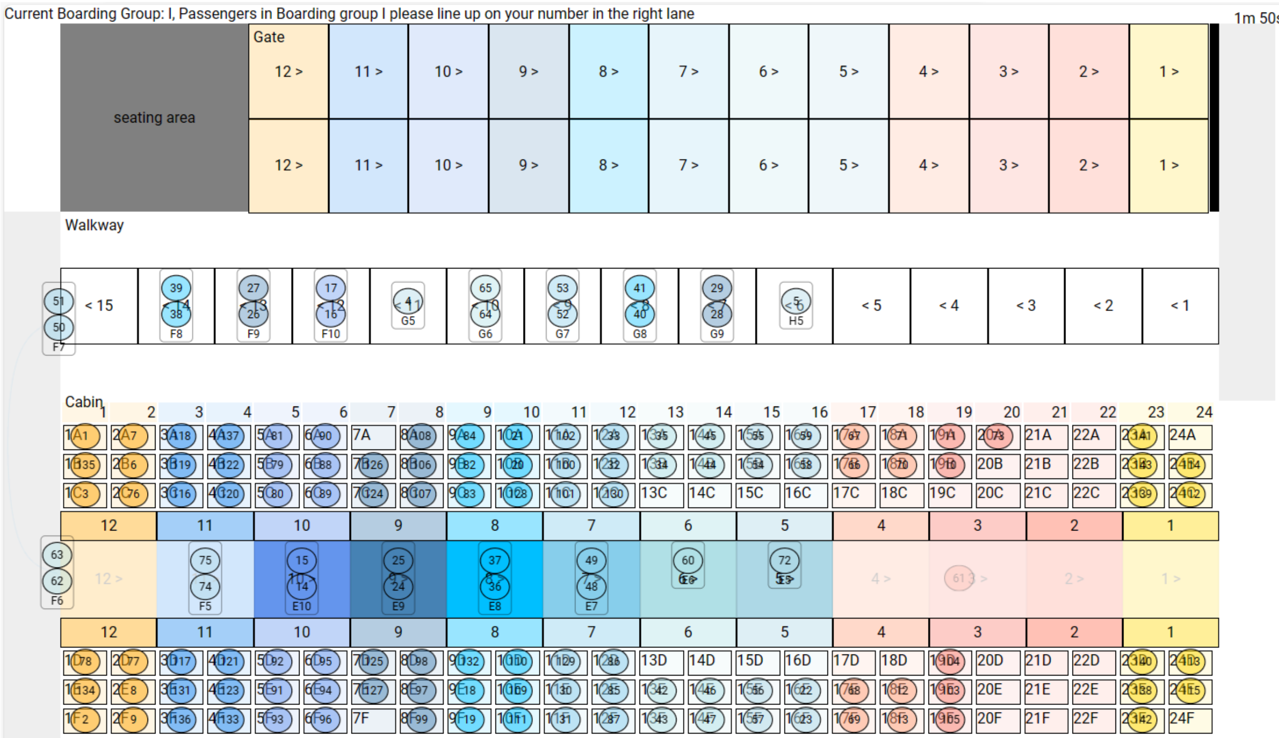
1 minute 17 seconds into the boarding process, the second parallel bottleneck occurs with Boarding Group C.



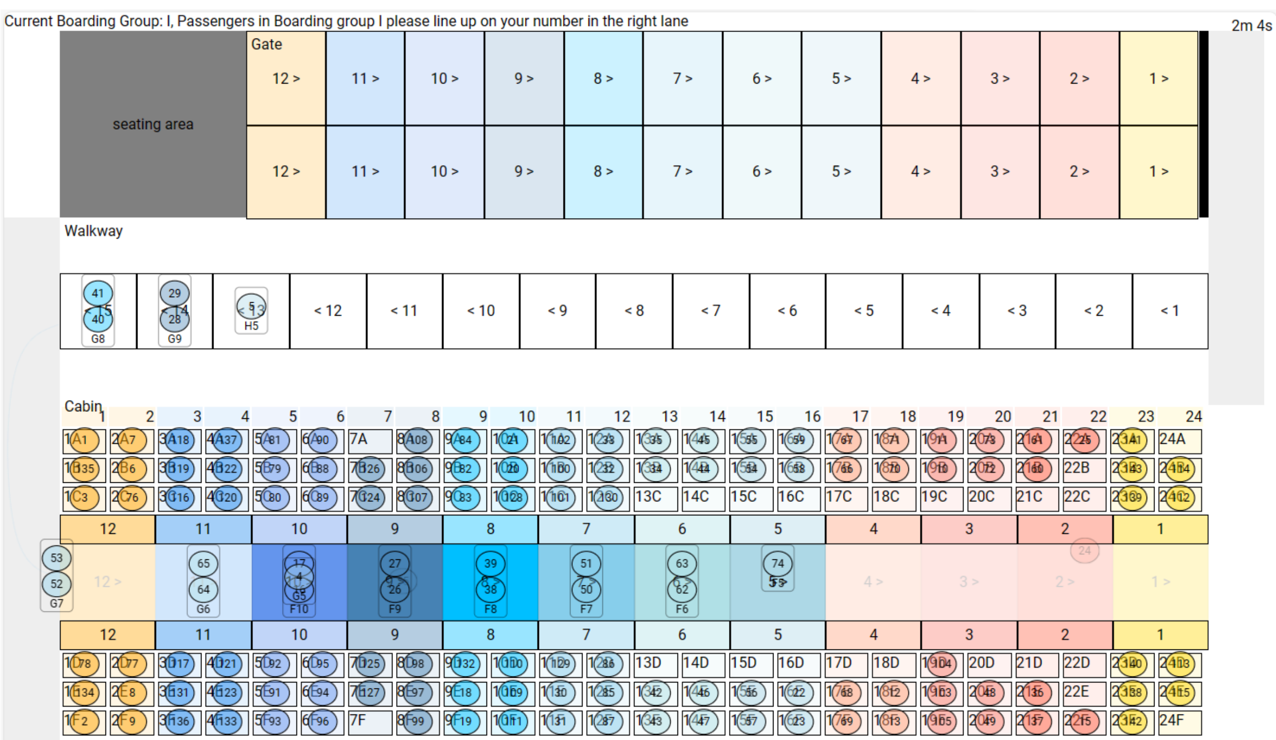
1 minute 34 seconds into the boarding process, the third parallel bottleneck occurs with Boarding Group D.



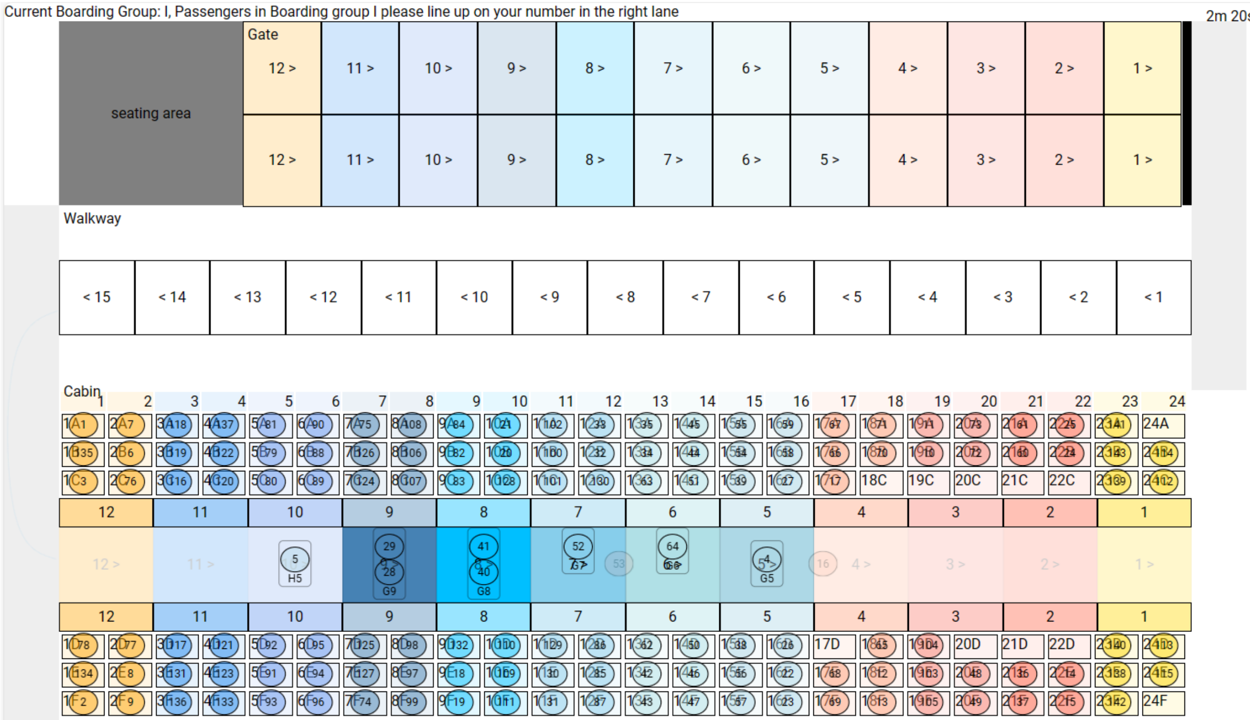
1 minute 50 seconds into the boarding process, the fourth parallel bottleneck occurs with Boarding Group E.



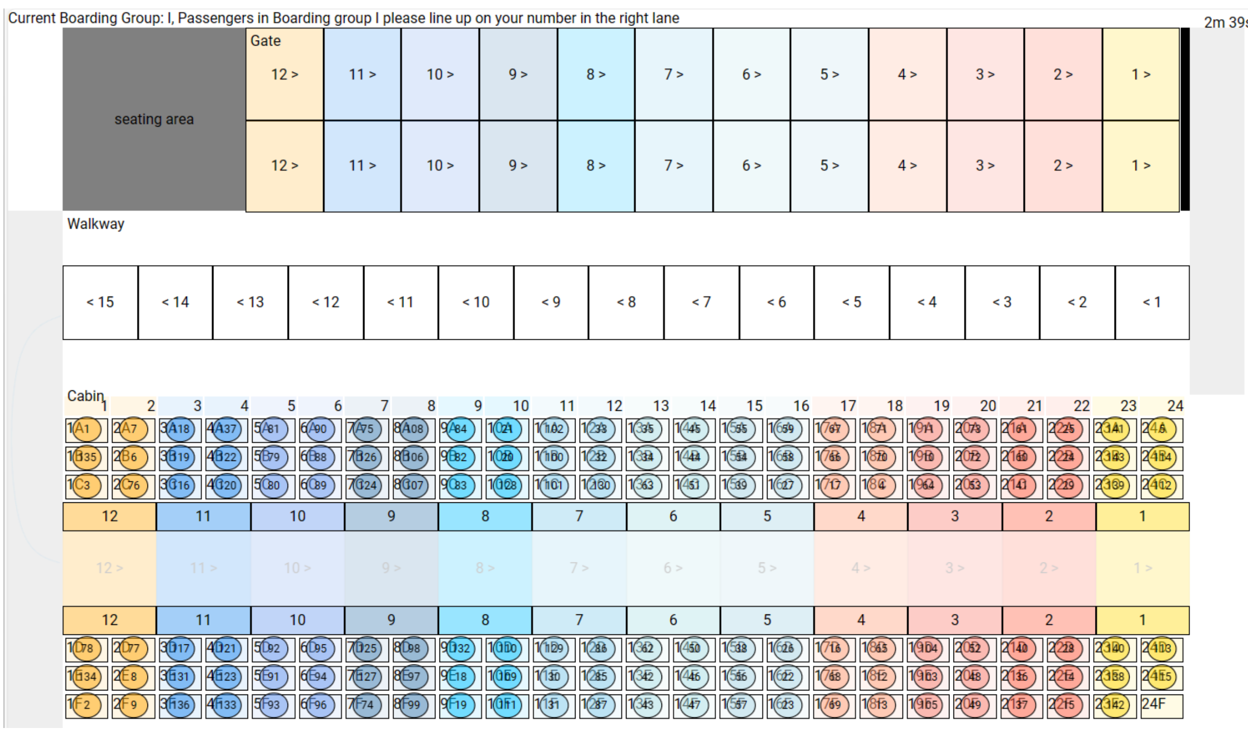
2 minutes 4 seconds into the boarding process, the fifth parallel bottleneck occurs with Boarding Group F.



2 minutes 20 seconds into the boarding process, the sixth parallel bottleneck occurs width Boarding Group G.



At 2 minutes 39 seconds into the boarding process, the final passenger is seated.



This simulation represents the best possible loading time given (Steffan 2008a) like constraints. Using more "real world" variables in the simulation results in loading times as fast as 3minutes 20seconds but averaging ~480 seconds or 8 minutes throwing in a few moments of chaos, indecision, user error, slow walkers, disabled people, etc.

Assumptions

The methodology described in this document will save time for both assigned and unassigned seating. Unassigned seating is assumed unless otherwise specified.

The model assumes a 737-300 with 24 rows of 6 seats and 24 bins of 6 slots in parallel. This symmetrical configuration (1 overhead bin slot per passenger, 2 rows per parallel bin pair) was chosen for clarity of comparison of certain data points because it makes nice round numbers. Certain symmetries were created with Steffan 2008a models (including but not limited to that study's 757 had 1 overhead bin slot per seat). The delta in outcome with regards to the seat to bin ratio in the Hughes methodology is negligible because the overhead bins are pre-allocated and we don't have a way to change the parameters of Steffan(2008a)'s experiments.

For a major airline, every minute saved in turn is worth millions per year. Reductive math extrapolating current value estimates into the last comprehensively publicly documented (2008) turn number is $96M/year per minute saved ($110/minute x 800 aircraft x 3-time critical turns /day x 365 days). Ultimately, we need to project the savings with values when the methodology will be rolled out. The Hughes methodology will likely save 8 minutes per turn or more than $771M/year, conservatively reported above.

https://www.zippia.com/advice/southwest-airlines-statistics/

Non-scientific, low sample rate, anecdotal observations of candid videos indicate the median average time it takes a passenger travelling solo to stow luggage is approximately 7.5 seconds (with a minimum of 3s and a reasonable max of 15 [includes re-stowing / adjusting]) with some outliers taking more than 20 seconds. 18 mins = 144 x 7.5 / 60 which obviously accounts for a great deal of boarding time. A passenger can stow 2 bags in an average of less than 4 seconds per bag.

Average humans can travel the length of a 737 cabin with a carry-on bag in tow in ~20 seconds without obstructions.

Some advantage in Hughes vs. Steffan:

- Families board together.
- There are boarding groups not one continuous long line stretching from the gate to the parking lot.
- There's more than ample room for new monetization.
- Every family member isn't expected to be able to load their own bag. The likelihood is that the most efficient family member to load bags into the overhead bins will take the lead without delay.
  - Although flight attendants and other passengers can be helpful, this methodology reduces the delay that might come from strangers interrupting getting themselves settled and/or pausing before offering to help each other as the family members will know ahead of time which other family members will be the fastest to load, who will need help,
  - Family members will likely will have firsthand knowledge of all the family member's bag's weight, family member capabilities and expectations ahead of time.
- Non-bag loading family members can prioritize getting themselves and other family members seated. Non-luggage handling family members will get to their seat faster than luggage-handling family members.
- Not all passengers are expected to be as physically fit or to be as trained as the "Hollywood stunt people" in the Steffan Air Hollywood experiments.
- Passengers aren't expected to pass each other in the isles.
- Passengers aren't limited to groups of 1 or 3.

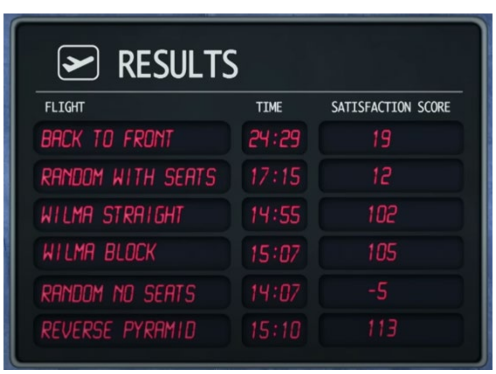
General advantages in Hughes method:

- **Reduced stress** for passengers and employees in knowing all passengers' (especially your family's) carry-on bags will have a **guaranteed place** on the aircraft, regardless of boarding group.
- Knowing exactly which bin all your family's carry-on bags go in (it will most likely be the bin behind the family who is stopped in front of them on the plane),

- The reduced stress that families won't have to be competing /wasting time interacting with other families for the same overhead bin (with in a boarding group [the people next to them in line]) and
- If a flight attendant does see a struggling passenger (causing a bottleneck), the flight attendant in the back of the plane will be able to identify the struggling passenger rapidly, get to them quickly and return to the back of the plane without causing an additional bottleneck.
- The natural reallocation of larger groups should reduce the bottlenecks caused by reseating in the boarding process.
- The distribution of passengers throughout the plane (by just using their assigned loading bins) will reduce the competition (in unassigned seating environments) / delay in seating time for seats for larger groups on board.
- A number of behind the scene optimizations can be computed before making reservations available (based on group size and time of reservation), assigning boarding groups and boarding group orders, for example: bins for larger groups can be assigned lower slot number (transparently by the system) to facilitate seat selection time.

Additional assumptions:

- Some passengers will do crazy, unpredictable things. For the purposes of the models, the crazy unpredictable things will likely affect all the models in a about the same way and therefor are negligible to the overall results. But there is some advantage to having less time to do crazy things, and there will be an overall improvement in morale and group cooperation by loading quickly. In the model, a chaos agent is included that adds an element of unpredictability at a random frame interval.
- Pre-loading passengers in wheelchairs or with other limitations affects all models basically the same way, so can be asserted as a constant.
- Passengers will prefer being as close to their carry-on bags as reasonably possible. In an unassigned seating environment, passengers will prioritize a preferred seat over the distance from their bag.
- Passengers will prefer facing their bags instead of having their bags behind them. This means passengers will stow their bags and intuitively walk towards the back of the plane to find their seat. This is one of the reasons it makes sense to allow non-carry-on passengers board first, to 'push' available seats back a few rows for efficiency.
    - An additional reason to prioritize non-carry-on passengers is to encourage passengers to reduce the number of carry-on-bags on board.
- Passengers can (to some degree) move backwards against the general flow of boarding traffic, but will likely not push past another passenger in line. This applies to everything that happens after the passenger is boarded (on the walk to the plane [in whatever form that takes]) and in the cabin.
- Passengers who miss boarding with their boarding group can board with a later boarding group on their number, but that wasn't included in the current model timings.



Reseats take 5s +10/-2

Faster loading methods with organization have the highest passenger satisfaction[xvii].

Variables

- Ps = Number of passengers
- W = Maximum time to walk the entire length of the aisle
- O = Time to store luggage in the overhead bin
- Z = Time to sit down
- r = Total number of rows in the plane

Definitions

1. **Row Number Calculation**:
   - Each passenger i is assigned to a row based on their order in the queue. The calculation of the row number for each passenger, where rows are filled sequentially from the back of the plane to the front:

$$\text{row\_number}_i = \left\lfloor \frac{i-1}{\frac{Ps}{r}} \right\rfloor + 1$$

2. **Distance Factor**:
   - A distance factor based on the passenger's row number relative to the total rows, which affects the walking time. This factor decreases as the row number increases (closer to the front):

$$\text{distance\_factor}_i = \frac{r - \text{row\_number}_i + 1}{r}$$

3. **Walking Time for Each Passenger**:
   - The walking time for each passenger i is a fraction of W, adjusted by their distance factor:

$$\text{walk\_time}_i = W \times \text{distance\_factor}_i$$

4. **Total Time for Each Passenger**:
   - The total time for each passenger i includes walking to their row, storing their luggage, and sitting down:

$$\text{time}_i = \text{walk\_time}_i + O + Z$$

5. **Total Loading Time**:
   - The sum of the total times for all passengers gives the entire loading time:

$$T = \sum_{i=1}^{Ps} \text{time}_i$$

Complete Mathematical Model

Combining all the components, the total loading time T for all passengers is given by:

$$T = \sum_{i=1}^{Ps} \left(W \times \frac{r - \left\lfloor \frac{i-1}{\frac{Ps}{r}} \right\rfloor + 1}{r} + O + Z \right)$$

But the straight math doesn't take time waiting for earlier passengers to board into account.

Markov chain Monte Carlo (MCMC) methods use computer simulation of Markov chains in the parameter space. The Markov chains are defined in such a way that the posterior distribution in the given statistical inference problem is the asymptotic distribution. This allows use of ergodic averages to approximate the desired posterior expectations. Several standard approaches to define such Markov chains exist, including Gibbs sampling, Metropolis–Hastings, and reversible jump. Using these algorithms, it is possible to implement posterior simulation in essentially any problem which allows point-wise evaluation of the prior distribution and likelihood function.

The MCMC scheme used is known as Gibbs sampling and is a method for generating a joint empirical distribution of multiple variables from a set of modeled conditional distributions for each variable when the structure of data is too complex to either implement mathematical formulas or directly simulate.

Markov chain Monte Carlo (MCMC; Tierney, 1994) involves drawing random samples with the help of a Markov chain from target distributions that are otherwise difficult to sample from. When applied in the fully Bayesian context, the target distribution is the joint posterior distribution of parameters. The samples from the Markov chain offer simple MCMC-based procedures have been proposed to estimate MIRT models (e.g., Béguin and Glas, 2001; Kim and Bolt, 2007; Edwards, 2010; Babcock, 2011), building upon previous work on MCMC estimation of unidimensional IRT models (e.g., Albert, 1992; Patz and Junker, 1999a,b). While applying MCMC algorithms, prior distributions of model parameters have to be specified. However, this has to be done with caution since the specification of priors will impact parameter estimates, even non-informative prior.

All outcomes to the various points of the model are recorded.

Seating

The algorithm used for seat selection is similar to Tetris. I approached seating preferences like variably sized Tetrominoes[4] with complex affinity. If we approach the Tetris board as a single dimension linear array (only shaping the array back into a board for the UI), we can use built in array tools to solve Tetris in 4 lines of code:

```
let row = board.length ? this.rowCount(board) + 1 : 0;         // start at the top of the board, if it has any blocks
while (row > 0 && !this.blocksInTheWay(shape, board, (row - 1), col)) { row--; }   // move down until you hit a block
shape.forEach((block: number) => { board[10 * row + col + block] = 1; });         // write the block to the board
board = this.joinRemainingBoardRows([...this.boardRows(board).filter(this.incompleteRows)]); // remove complete rows
```

[3 lines of code for this example because we're not trying to remove rows of completed seats.]

It doesn't matter if passengers select seats first or overhead bins first, the algorithm is the same for the purposes of the model. But, in an unassigned seating condition we can reverse engineer the optimum overhead bin placement by gaming out the likely chosen seats.

The model assumes passengers generally prefer to remain as close to their other family members as possible and to be as close to their carry-on bags as reasonably possible. However, if faced with a choice between a preferred seat, separating the family and proximity to their bag, this model assumes passengers will prioritize uniting the family then their seat preference, then the bag proximity. There is also a strong preference to sit in the same row with the other members of the family if possible, as opposed to the same seats in multiple rows.

This system uses two lists (**orderOfPrefForPreferredSeating** and **orderOfPrefForSecondarySeating**) to rank seat rows based on their desirability. The list is ordered such that starting with a target row (corresponding to the assigned overhead bin [x2 in this instance]), passengers will travel a certain distance forward and aft to find a preferred seat.

Bin: 1, Target Row: 23
Bin: 2, Target Row: 21
Bin: 3, Target Row: 19
Bin: 4, Target Row: 17
Bin: 5, Target Row: 15
Bin: 6, Target Row: 13
Bin: 7, Target Row: 11
Bin: 8, Target Row: 9
Bin: 9, Target Row: 7
Bin: 10, Target Row: 5
Bin: 11, Target Row: 3
Bin: 12, Target Row: 1

For 1 traveler in the family in the order of window, then isle, before accepting a secondary preference like a middle seat (WIlMa). With a 60/40 preference for windows, and a tendency to find seating on the same side of the isle as their luggage. Furthermore, passengers are more likely to exaggerate that behavior a multiple of seeking seats towards the aft (rear) of the plane over seats towards the front of the plane.

This lists below contain a series of objects, each representing a range of rows and their corresponding desirability order. Each object specifies:

[4] https://en.wikipedia.org/wiki/Tetromino

- **startRow**: The starting row number of the seat block from the target row.
- **endRow**: The ending row number of the seat block from the target row.
- **order**: A numeric value indicating the desirability of the seat block, with lower values indicating higher preference.

Example Entries Explained:

- **{ startRow: 1, endRow: 1, order: 1 }** in **orderOfPrefForPreferredSeating** indicates that row 1 is the most preferred seating location.
- **{ startRow: 9, endRow: 10, order: 6 }** suggests that rows 9 and 10 are less preferred compared to row 1 but more preferred compared to later rows.
- **{ startRow: -9, endRow: -10, order: 15 }** implies a special seating configuration for rows 9 and 10, which are highly desirable under specific circumstances.

For each group size, a different set of seat preferences is applied, in the same way that passengers travelling solo will prefer windows, then isles, then middle seats, with a preference for 1 side of the airplane or the other. At least one passenger in each family will try for the same WIlMa. It is unlikely that a party of 6 will choose 6 middle seats on alternating sides of the plane spread throughout the plane, when a full row is immediately available.

Passengers travelling in pairs will try to sit next to each other. Passengers travelling in a group of 3 will try to take a whole side of a row as a first preference. Passengers travelling in groups of 4 prefer to stay in one row, then break up into a 2x2 formation. Passengers travelling in a group of 6 will try to take a whole row, then break up into a set of 3x3 on the same side of the isle.

After a desirable seat is found, the distance to the seat from the target row is recorded

`In the same way that Tetrominoes can be expressed as linear arrays,`

```
public Shapes = {
    Q: [0, 1, 10, 11],
    Z: [1, 2, 10, 11],
    S: [0, 1, 11, 12],
    T: [1, 10, 11, 12],
    I: [0, 1, 2, 3],
    L: [0, 1, 10, 20],
    J: [0, 1, 11, 21]
  };
```

`We can convert the array of seat letters into an array of offsets and apply the linear array methodology.`

The following sequence demonstrates passengers in unassigned seating selecting seats based on bin location and family size per the above algorithm. The families are grouped into blocks (unlike the simulation above where they are seated individually) for clarity of the effect of the spacing created with the Hughes methodology.

```
Selected seat for the first passenger with no carry on luggage
     1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24
 A  ██   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X
 B   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X
 C   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X
 D   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X
 E   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X
 F   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X   X
```

`The remained of the sequence (Tetris game played out) is below`

```
orderOfPrefForPreferredSeating : any = [
    { startRow: 1, endRow: 1, order: -2 }, // highest preference
    { startRow: 2, endRow: 2, order: 1 },
    { startRow: 3, endRow: 6, order: 3 },
    { startRow: 7, endRow: 8, order: 8 },
    { startRow: 9, endRow: 10, order: 6 },
    { startRow: -1, endRow: -1, order: -1 },
    { startRow: -2, endRow: -2, order: 2 },
    { startRow: -3, endRow: -4, order: 4 },
    { startRow: -5, endRow: -6, order: 9 },
    { startRow: -7, endRow: -8, order: 12 },
    { startRow: -9, endRow: -10, order: 15 },
  ];

  orderOfPrefForSecondarySeating: any = [
    { startRow: 1, endRow: 3, order: 5 },
    { startRow: 4, endRow: 6, order: 10 },
    { startRow: 7, endRow: 8, order: 13 },
    { startRow: 9, endRow: 10, order: 16 },
    { startRow: -1, endRow: -2, order: 7 },
    { startRow: -3, endRow: -4, order: 11 },
    { startRow: -5, endRow: -6, order: 14 },
    { startRow: -7, endRow: -8, order: 17 },
    { startRow: -9, endRow: -10, order: 18 },  // lowest preference
  ];
```

```
// Singles Preferred seating window priority port:
let AFCD = this.letterToSeat("A,F,C,D"); // [[1], [6], [3], [4]]

// Singles Preferred seating window priority starboard:
let FADC = this.letterToSeat("F,A,D,C"); // [[6], [4], [3], [1]];

// Singles Preferred seating isle then window port:
let CDAF = this.letterToSeat("C,D,A,F"); // [[4], [6], [1], [3]];

// Singles Preferred seating isle then window starboard:
let DCFA = this.letterToSeat("D,C,F,A"); // [[3], [1], [6], [4]];

// Singles Secondary Preference seating window priority starboard:
let BE = this.letterToSeat("B,E"); // [[5], [2]];

// Singles Secondary Preference seating isle then window port:
let EB = this.letterToSeat("E,B"); // [[2], [5]];
```

Selected Seats for group 22, no carry on luggage

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Selected Seats for group 23, no carry on luggage

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Selected Seats for group 24, no carry on luggage

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Selected Seats for group 25, no carry on luggage

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Selected Seats for group 26, no carry on luggage

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F	███	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Selected Seats for group 49, no carry on luggage

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	███	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F	███	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Selected Seats for group 44 bin: 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	X	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	█
F	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	█

Selected Seats for group 39 bin: 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	X	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	█	X	█
F	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	█	X	█

Selected Seats for group 34 bin: 3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	X	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	█	X	█	X	█
F	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	█	X	█	X	█

Selected Seats for group 29 bin: 4

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	X	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
E	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	█	X	█	X	█	X	█
F	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	█	X	█	X	█	X	█

Selected Seats for group 58 bin: 5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	█	X	X	X	X	X	X	X	X
E	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	█	X	█	X	█	X	█	X	█
F	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	█	X	█	X	█	X	█	X	█

Selected Seats for group 55 bin: 6

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	█	█	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	█	█	X	X	X	X	X	X	X	X	X	X	X	█	X	█	X	X	X	X	X	X	X	X
E	█	X	X	X	X	X	X	X	X	X	X	X	X	█	X	█	X	█	X	█	X	█	X	█
F	█	█	X	X	X	X	X	X	X	X	X	X	X	█	X	█	X	█	X	█	X	█	X	█

Selected Seats for group 52 bin: 7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	███	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	███	███	X	X	X	X	X	X	X	X	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	X	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	X	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 64 bin: 8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	X	X	X	X	X	X	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	███	X	X	X	X	X	X	X	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	███	███	X	X	X	X	X	X	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	X	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	X	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 62 bin: 9

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	X	X	X	X	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	███	X	X	X	X	X	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	███	███	X	X	X	X	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	███	███	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	X	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	X	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 60 bin: 10

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	X	X	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	███	X	X	X	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	███	███	X	X	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	███	███	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	X	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	X	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 66 bin: 11

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	███	X	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	███	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	X	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	X	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 68 bin: 12

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	███	X	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 45 bin: 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	███
B	███	X	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	███
C	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 40 bin: 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	███	X	███
B	███	X	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	███	X	███
C	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 35 bin: 3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	███	X	███	X	███
B	███	X	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	███	X	███	X	███
C	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 30 bin: 4

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███
B	███	X	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███
C	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 59 bin: 5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	███	X	███	X	███	X	███	X	███
B	███	X	███	███	X	███	X	███	X	███	X	X	X	X	X	███	X	███	X	███	X	███	X	███
C	███	███	███	███	X	███	X	███	X	███	X	X	X	X	X	███	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 56 bin: 6

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	X	X	███	X	███	X	███	X	███	X	███	X	███
B	███	X	███	███	X	███	X	███	X	███	X	X	X	███	X	███	X	███	X	███	X	███	X	███
C	███	███	███	███	X	███	X	███	X	███	X	X	X	███	X	███	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 53 bin: 7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
B	███	X	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
C	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	X	███

Selected Seats for group 46 bin: 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
B	███	X	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
C	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	███	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	X	███	███	███

Selected Seats for group 41 bin: 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
B	███	X	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
C	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	███	███	███	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	X	███	███	███	███	███

Selected Seats for group 36 bin: 3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
B	███	X	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
C	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	X	███	███	███	███	███	███	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	X	███	███	███	███	███	███	███

Selected Seats for group 31 bin: 4

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
B	███	X	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
C	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	X	X	X	███	X	███	X	███	███	███	███	███	███	███	███	███
F	███	███	███	X	X	X	X	X	X	X	X	███	X	███	X	███	███	███	███	███	███	███	███	███

Selected Seats for group 50 bin: 8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
B	███	X	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███	X	███
C	███	███	███	███	X	███	X	███	X	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
D	███	███	███	███	X	███	X	███	███	███	X	███	X	███	X	███	X	X	X	X	X	X	X	X
E	███	X	███	███	X	X	X	X	███	X	X	███	X	███	X	███	███	███	███	███	███	███	███	███
F	███	███	███	X	X	X	X	X	███	X	X	███	X	███	X	███	███	███	███	███	███	███	███	███

```
Selected Seats for  group 63 bin:  9
    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24
A ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X ███   X ███   X ███   X ███   X ███   X ███
B ███   X ███ ███   X ███ ███ ███   X ███   X ███   X ███   X ███   X ███   X ███   X ███   X ███
C ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X ███   X ███   X   X   X   X   X   X   X   X
D ███ ███ ███ ███   X ███ ███ ███ ███ ███   X ███   X ███   X ███   X   X   X   X   X   X   X   X
E ███   X ███ ███   X   X   X   X ███   X   X ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███
F ███ ███ ███   X   X   X   X   X ███   X   X ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███

Selected Seats for  group 61 bin:  10
    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24
A ███ ███ ███ ███ ███ ███ ███ ███   X ███   X ███   X ███   X ███   X ███   X ███   X ███   X ███
B ███   X ███ ███ ███ ███ ███ ███   X ███   X ███   X ███   X ███   X ███   X ███   X ███   X ███
C ███ ███ ███ ███ ███ ███ ███ ███   X ███   X ███   X ███   X ███   X   X   X   X   X   X   X   X
D ███ ███ ███ ███ ███ ███ ███ ███ ███ ███   X ███   X ███   X ███   X   X   X   X   X   X   X   X
E ███   X ███ ███   X   X   X   X ███   X   X ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███
F ███ ███ ███   X   X   X   X   X ███   X   X ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███

Selected Seats for  group 67 bin:  11
    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24
A ███ ███ ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X ███   X ███   X ███   X ███
B ███   X ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X ███   X ███   X ███   X ███
C ███ ███ ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X   X   X   X   X   X   X   X
D ███ ███ ███ ███ ███ ███ ███ ███ ███ ███ ███ ███   X ███   X ███   X   X   X   X   X   X   X   X
E ███   X ███ ███   X   X   X   X ███   X ███ ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███
F ███ ███ ███   X   X   X   X   X ███   X   X ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███

Selected Seats for  group 47 bin:  1
    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24
A ███ ███ ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X ███   X ███   X ███ ███ ███
B ███   X ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X ███   X ███   X ███ ███ ███
C ███ ███ ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X   X   X   X   X   X   X   X
D ███ ███ ███ ███ ███ ███ ███ ███ ███ ███ ███ ███   X ███   X ███   X   X   X   X   X   X   X   X
E ███   X ███ ███   X   X   X   X ███   X ███ ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███
F ███ ███ ███   X   X   X   X   X ███   X   X ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███

Selected Seats for  group 42 bin:  2
    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24
A ███ ███ ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X ███   X ███ ███ ███ ███ ███
B ███   X ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X ███   X ███ ███ ███ ███ ███
C ███ ███ ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X   X   X   X   X   X   X   X
D ███ ███ ███ ███ ███ ███ ███ ███ ███ ███ ███ ███   X ███   X ███   X   X   X   X   X   X   X   X
E ███   X ███ ███   X   X   X   X ███   X ███ ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███
F ███ ███ ███   X   X   X   X   X ███   X   X ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███

Selected Seats for  group 37 bin:  3
    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24
A ███ ███ ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X ███ ███ ███ ███ ███ ███ ███
B ███   X ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X ███ ███ ███ ███ ███ ███ ███
C ███ ███ ███ ███ ███ ███ ███ ███   X ███ ███ ███   X ███   X ███   X   X   X   X   X   X   X   X
D ███ ███ ███ ███ ███ ███ ███ ███ ███ ███ ███ ███   X ███   X ███   X   X   X   X   X   X   X   X
E ███   X ███ ███   X   X   X   X ███   X ███ ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███
F ███ ███ ███   X   X   X   X   X ███   X   X ███   X ███   X ███ ███ ███ ███ ███ ███ ███ ███ ███
```

Group 42 and 37 would push back in parallel

Selected Seats for group 32 bin: 4

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	X	█	█	█	X	█	X	█	█	█	█	█	█	█	█	█
B	█	X	█	█	█	█	█	█	X	█	█	█	X	█	X	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	X	█	█	█	X	█	X	█	X	X	X	X	X	X	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	█	X	X	X	X	X	X	X	X
E	█	X	█	█	X	X	X	X	█	X	█	█	X	█	X	█	█	█	█	█	█	█	█	█
F	█	█	█	X	X	X	X	X	█	X	X	█	X	█	X	█	█	█	█	█	█	█	█	█

Selected Seats for group 27 bin: 5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	X	█	█	█	X	█	X	█	█	█	█	█	█	█	█	█
B	█	X	█	█	█	█	█	█	X	█	█	█	X	█	X	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	X	█	█	█	X	█	X	█	X	X	X	X	X	X	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	█	X	X	X	X	X	X	X	X
E	█	X	█	█	X	X	X	X	█	X	█	█	X	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	X	X	X	X	X	█	X	X	█	X	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 57 bin: 6

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	X	█	█	█	X	█	X	█	█	█	█	█	█	█	█	█
B	█	X	█	█	█	█	█	█	X	█	█	█	X	█	X	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	X	█	█	█	X	█	X	█	X	X	X	X	X	X	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X	X	X	X	X	X	X
E	█	X	█	█	X	X	X	X	█	X	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	X	X	X	X	X	█	X	X	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 54 bin: 7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	X	█	█	█	█	█	X	█	█	█	█	█	█	█	█	█
B	█	X	█	█	█	█	█	█	X	█	█	█	█	█	X	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	X	█	█	█	█	█	X	█	X	X	X	X	X	X	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X	X	X	X	X	X	X
E	█	X	█	█	X	X	X	X	█	X	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	X	X	X	X	X	█	X	X	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 8 bin: 9

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	X	█	█	█	█	█	X	█	█	█	█	█	█	█	█	█
B	█	X	█	█	█	█	█	█	X	█	█	█	█	█	X	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	X	█	█	█	█	█	X	█	X	X	X	X	X	X	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X	X	X	X	X	X	X
E	█	X	█	█	X	X	X	X	█	X	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	X	X	X	X	█	█	X	X	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 4 bin: 10

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	X	█	█	█	█	█	X	█	█	█	█	█	█	█	█	█
B	█	X	█	█	█	█	█	█	X	█	█	█	█	█	X	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	X	█	█	█	█	█	X	█	X	X	X	X	X	X	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X	X	X	X	X	X	X
E	█	X	█	█	X	X	X	X	█	X	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	X	X	█	X	█	█	X	X	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 65 bin: 12

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	██	██	██	██	██	██	██	██	X	██	██	██	██	██	X	██	██	██	██	██	██	██	██	██
B	██	██	██	██	██	██	██	██	X	██	██	██	██	██	X	██	██	██	██	██	██	██	██	██
C	██	██	██	██	██	██	██	██	X	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
D	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
E	██	██	██	██	X	X	X	X	██	X	██	██	██	██	██	██	██	██	██	██	██	██	██	██
F	██	██	██	██	██	██	██	██	██	X	X	██	██	██	██	██	██	██	██	██	██	██	██	██

Selected Seats for group 17 bin: 6

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	██	██	██	██	██	██	██	██	X	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██
B	██	██	██	██	██	██	██	██	X	██	██	██	██	██	X	██	██	██	██	██	██	██	██	██
C	██	██	██	██	██	██	██	██	X	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
D	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
E	██	██	██	██	X	X	X	X	██	X	██	██	██	██	██	██	██	██	██	██	██	██	██	██
F	██	██	██	██	██	██	██	██	██	X	X	██	██	██	██	██	██	██	██	██	██	██	██	██

Selected Seats for group 14 bin: 7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	██	██	██	██	██	██	██	██	X	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██
B	██	██	██	██	██	██	██	██	X	██	██	██	██	██	X	██	██	██	██	██	██	██	██	██
C	██	██	██	██	██	██	██	██	X	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
D	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
E	██	██	██	██	X	X	X	X	██	X	██	██	██	██	██	██	██	██	██	██	██	██	██	██
F	██	██	██	██	██	██	██	██	██	X	██	██	██	██	██	██	██	██	██	██	██	██	██	██

Selected Seats for group 51 bin: 8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██
B	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	██	██	██	██	██	██	██	██
C	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
D	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
E	██	██	██	██	X	X	X	X	██	X	██	██	██	██	██	██	██	██	██	██	██	██	██	██
F	██	██	██	██	██	██	██	██	██	X	██	██	██	██	██	██	██	██	██	██	██	██	██	██

Selected Seats for group 9 bin: 9

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██
B	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	██	██	██	██	██	██	██	██
C	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
D	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
E	██	██	██	██	X	X	X	X	██	X	██	██	██	██	██	██	██	██	██	██	██	██	██	██
F	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██

Selected Seats for group 5 bin: 10

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██
B	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	██	██	██	██	██	██	██	██
C	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
D	██	██	██	██	██	██	██	██	██	██	██	██	██	██	X	██	X	X	X	X	X	X	X	X
E	██	██	██	██	X	██	X	X	██	X	██	██	██	██	██	██	██	██	██	██	██	██	██	██
F	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██

Selected Seats for group 48 bin: 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
B	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
C	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	X	X	X	X	X	X	X	X
D	███	███	███	███	███	███	███	███	███	███	███	███	███	███	X	███	X	X	X	X	X	X	X	X
E	███	███	███	███	X	███	X	X	███	X	███	███	███	███	███	███	███	███	███	███	███	███	███	███
F	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███

Selected Seats for group 43 bin: 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
B	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
C	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	X	X	X	X	X	███	X	X
D	███	███	███	███	███	███	███	███	███	███	███	███	███	███	X	███	X	X	X	X	X	███	X	X
E	███	███	███	███	X	███	X	X	███	X	███	███	███	███	███	███	███	███	███	███	███	███	███	███
F	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███

Selected Seats for group 38 bin: 3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
B	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
C	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	X	X	X	███	X	███	X	X
D	███	███	███	███	███	███	███	███	███	███	███	███	███	███	X	███	X	X	X	███	X	███	X	X
E	███	███	███	███	X	███	X	X	███	X	███	███	███	███	███	███	███	███	███	███	███	███	███	███
F	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███

Selected Seats for group 33 bin: 4

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
B	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
C	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	X	███	X	███	X	███	X	X
D	███	███	███	███	███	███	███	███	███	███	███	███	███	███	X	███	X	███	X	███	X	███	X	X
E	███	███	███	███	X	███	X	X	███	X	███	███	███	███	███	███	███	███	███	███	███	███	███	███
F	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███

Selected Seats for group 20 bin: 5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
B	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
C	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	X	███	X	███	X	███	X	X
D	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	X	███	X	███	X	███	X	X
E	███	███	███	███	X	███	X	X	███	X	███	███	███	███	███	███	███	███	███	███	███	███	███	███
F	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███

Selected Seats for group 18 bin: 6

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
B	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	█	X	X
E	█	█	█	█	X	█	X	X	█	X	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 15 bin: 7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
B	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	█	X	X
E	█	█	█	█	X	█	X	X	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 12 bin: 8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
B	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	█	X	X
E	█	█	█	█	X	█	X	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 10 bin: 9

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
B	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	█	X	X
E	█	█	█	█	X	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 6 bin: 10

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
B	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	█	X	X
E	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 2 bin: 11

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
B	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X
E	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 21 bin: 5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
B	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	█	X	X
E	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 19 bin: 6

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
B	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	X
E	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 16 bin: 7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
B	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X	X
E	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

Selected Seats for group 13 bin: 8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
B	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
C	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X
D	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	X
E	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
F	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

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Selected Seats for  group 11 bin:  9
```

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
B	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
C	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
D	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	X
E	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███
F	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███	███

Boarding starts when the first passenger's ticket is scanned (before they enter the walkway to the plane). Boarding is complete when the last passenger takes their seat.

The pathway is represented by a 1 dimensional linear array.

Every time a bottle neck is hit in the linear array, it is recorded to identify hot spots, which are represented by the color diagrams above.

Live Demo: https://202405boardbyoverheadbinv3.netlify.app/

source Code for current version of the seat selection heuristic: https://github.com/JeffHughes/2024-05-BoardingSimulationV3-API/blob/master/Calculations/6.Seats.cs

source code that will generate the block diagrams:

https://github.com/JeffHughes/2024-04-BoardingSimulationV1/blob/master/src/app/services/seats3.service.ts

https://github.com/JeffHughes/2024-04-BoardingSimulationV1/blob/master/src/app/services/console.service.ts

Full Source Code:

https://github.com/JeffHughes/2024-05-BoardingSimulationV3-API

https://github.com/JeffHughes/2024-05-AirplaneBoardingSimulatorV3Client

Disclaimers

This draft is not intended for public distribution or scientific peer review.

Primarily for clarity, sections (defined as 2 words or more) from the included text are copied verbatim or near verbatim from their sources, additionally some sections were suggested or revised via AI where original source material was opaque to the author. See end notes/bibliography for references to complete original source material where available.

Practicality and limitations of computer simulations

It is critical that readers of this document understand this idea is only a few days old and that computer simulations aren't real world tests and no market studies have been conducted.

Airlines would need to ensure passenger compliance with the new system, which could involve educating passengers about the process before boarding, during and even before booking.

Although changes would be as minimal as possible, airlines will need to modify their boarding infrastructure and digital systems to accommodate pre-assigned bin spaces.

The success of this system hinges on rigorous testing and possibly phased rollouts to gauge passenger reactions and refine the process based on real-world feedback.

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[i] Reductive math extrapolating current value estimates into the last comprehensively publicly documented (2008) turn number is $96M/year per minute saved ($110/minute x 800 aircraft x 3-time critical turns /day x 365 days). Ultimately, we need to project the savings with values when the methodology will be rolled out. The Hughes methodology will likely save 8 minutes per turn or more than $771M/year, conservatively reported above as $750M.

[ii] Previous studies of the airplane boarding used a variety of approaches. Pioneering work done by Van Landeghem & Beuselinck (2002) used computer simulations of several boarding schemes and found there is much room for improvement over traditional back-to-front boarding. Of particular interest is that they point out that random boarding is superior to many traditional methods. A later computer simulation study (van den Briel et al., 2005) confirmed that traditional methods are not optimal, even in light of different assumptions regarding the primary cause of delay in the boarding process. Analytic work by Bachmat et al. (2006), which modeled optimal airplane boarding as an extremal path in a two-dimensional, Lorentzian geometry, broadly confirmed the findings of Van Landeghem & Beuselinck (2002) and was able to interpret those findings in the context of their model—thus providing an ex planation for why the different boarding strategies perform as they do relative to each other. – Steffan 2008

[iii] Jason H. Steffen conducted several important experiments on airplane boarding methods, including a notable experiment called Air Hollywood, setup on a soundstage in California. In his research, Steffen explored various boarding strategies and published his findings in peer-reviewed journals like the Journal of Air Transport Management. His work focused on optimizing the boarding process, suggesting that parallelizing the boarding process rather than serializing it could significantly speed up boarding times. The experiments were held on a mock Boeing 757 to simulate real-world boarding conditions. https://ar5iv.labs.arxiv.org/html/0802.0733 One of Steffen's papers titled "Experimental test of airplane boarding methods" detailed this experiment and compared the effectiveness of multiple boarding strategies, including the Steffen method, which proved to be among the most efficient. This particular study is often referenced in discussions about optimizing boarding times and methods in available online research.

[iv] https://youtu.be/oAHbLRjF0vo?si=nKD1kZS6xJNZLyFB&t=332

[v] Steffan's model is heavily penalized in my simulation for lack of practicality. There is no room at an airport gate for a single line of passengers. It's impossible for that many passengers to self-organize into a single line. There must be boarding groups. Families want to travel together. Expecting all passengers to be in groups of 1 or 3 is

unreasonable. Expecting passengers (in groups/families) to efficiently pass each other in an isle is unrealistic. https://www.youtube.com/watch?v=o9-XjEI8VmA Boarding the left side of the plane, then the right creates a new set of bottlenecks. Not all passengers are Hollywood stunt men that are capable of assumed feats. People do crazy unpredictable things, etc.

[vi] The stickers on the floor at the gate and stickers in the cabin on the overhead bins (perhaps a flag) are the only physical hardware changes necessary to implement the methodology.

[vii] Gates will be configured for the largest aircraft they can handle, not all reserved spaces will be used on every flight.

[viii] In part because large groups are more likely to occupy whole rows and even more likely to occupy middle seats.

[ix] Giving families with very young children boarding order 1 in early boarding groups accomplishes 2 tasks; 1: if they are directly behind a large group, their slower speed won't be as big a factor, (as the **only** slowdown in the current model is between the end of the early boarding groups and the beginning of the next, 2: it helps get them "out of the way," if they need time in the isle that would otherwise block other passengers.

[x] Making a big deal about testing it could stir up as much publicity as desired, whether the public feedback is good or bad. Hughes has 2 ideas for angles to enhance the attractiveness of the story to the media at large.

[xi] This could be particularly compelling if tied to additional newsworthy verticals such as: sustainability goals, as faster boarding times could indirectly lead to reduced fuel consumption and emissions.

[xii] Source code for the demo: https://github.com/JeffHughes/2024-05-BoardingSimulationV3-API

running code: https://202405boardbyoverheadbinv3.netlify.app/

API: https://github.com/JeffHughes/2024-05-AirplaneBoardingSimulatorV3Client

[xiii] The following were considered and an average was selected: Business travel: Historically, a substantial portion of air travel, particularly on weekdays and on major routes between business hubs, consists primarily of solo travelers. These travelers are typically flying for work-related reasons. Leisure travel: Leisure travelers are more likely to travel in groups, which could include families, couples, or friends traveling together, especially during holiday seasons and weekends. Demographic factors: Younger travelers, such as millennials, often have a higher propensity to travel alone compared to older demographics, influenced by trends in solo travel and experiences.

[xiv] The absolute maximum number of boarding groups would be equal to the number of slots in the overhead bins for the plane x 2, or 12 in this instance A,B,C,D,E,F,G,H,I,J,K,L. The only way to populate boarding group L is if EVERY passenger is travelling solo. In the example data, there are 68 families. 143/68 = 2.1 average family size.

[xv] 6-abreast: 17 in (43.2 cm), 5-abreast: 19 in (48.3 cm), 4-abreast: 21 in (53.3 cm).

[xvi] Specifically Boeing Space Bins

[xvii] Villalobos and van den Briel presented America West with a boarding approach called the **reverse** pyramid that calls for simultaneously loading an aircraft from back to front and outside in. Window and middle passengers near the back of the plane board first; those with aisle seats near the front are called last. Passengers are segregated into boarding groups based on their seat positions. Research has shown that this method minimizes incidents of passenger interference and results in faster boarding times. Airlines implementing the reverse pyramid have reported reduced departure delays and shorter average boarding times.