"Too Much Personal Baggage"
And Other Variables Affecting Airplane Boarding Times

Problem Restatement

Efficient algorithms are needed in order to optimize the time it takes people to board a plane, stow their luggage, and sit down. If major airlines around the world could shave a few minutes off the boarding process they would certainly save millions of dollars in overhead and lost productivity. It is necessary to run algorithms in different sized aircraft to weigh the potential pros and cons of each strategy.

Introduction

While researching the current strategies on airplane boarding we came across many variables that affect the boarding time. These variables include the passengers in the aisles, passengers trying to stow their baggage, and passengers already sitting who are blocking access to seats. Other variables include the number of passengers and the size and dimensions of the aircraft. Once we determined the range and type of the variables we were able to develop a computer model.

We decided that a computer simulation would be the most efficient way to compare multiple boarding strategies and model the problem. Our computer simulation allowed for greater precision in trying and manipulating variables. In this way, we were able to compare and contrast the variables. All we had to do was change a few variables and run the program again which was much easier than doing calculations by hand. Three current boarding strategies were modeled in the computer simulation. These included the "window, middle, aisle," "back to front," and "random" strategies which are explained in more detail later in the paper. The computer code acts as the brain of every passenger by calculating where they were going to move and analyzing whether or not there was space available. The hardest part about creating the model was developing how the passengers on the plane would react in different situations.

Assumptions and Justifications

A1. There are no major changes in aircraft design. The standard setup involving a single aisle with some variable number of seats on the left and right apply.
J1. This was done in order to simplify the model.

A2. Every passenger understands the system. People will participate willingly in each boarding strategy and not deviate or get up once they sit down.
J2. This was done in order to simplify the model.

A3. All passengers are the same physical size.
J3. This was done in order to simplify the model.

A4. There is no pre-boarding.
J4. This was done in order to simplify the model.

A5. All passengers move at the same speed.
J5. This was done in order to simplify the model.

A6. There are no seat classifications (first class and coach).
J6. This was done in order to simplify the model.

A7. For planes with multiple aisles passengers will not interfere with actions across aisles. The aisles are split in two, calculated, and then added together.
J7. This was done in order to simplify the model.

A8. The de-boarding process cannot be organized more efficiently due to the self-management of human nature.
J8. This is based on psychological considerations of social groups.

Current Strategies

Back to Front Strategy:

Most airlines today use a method called “Back to Front”. Passengers are loaded on to the plane in groups by row number. The first group to board is the one that will sit at the back of the plane. In this way, the aisle space is efficiently used because passengers do not crowd the front of the aircraft.

The benefits of this strategy are its simplicity and the fact that most people can understand it. It is currently the most widely used strategy of boarding an airplane and almost everyone who has flown has encountered it. Due to this fact, passengers have no reason not to assume that it is the best strategy. Without a true understanding of the mathematics behind boarding strategies, no one can get upset with this valid strategy. The “Back to Front” strategy also allows for families and groups to board together. Unlike other strategies, this “grouping” of passengers can be accounted for without too much preprocessing.

The disadvantage to this strategy is the potential for seat interference. Seat interference occurs when one passenger who is already sitting needs to be passed by another passenger heading to their own seat in the same row. Since there is no boarding order for window, middle, or aisle seats this seat interference occurs.

Random Strategy:

One of the latest and most interesting strategies to be deployed by Southwest Airlines is a random strategy. Passengers board the plane in a first-come first-serve basis. Passengers who arrive at the airport early have the benefit of boarding the plane first. This benefit includes the coveted exit row seats which are known to veteran travelers because of the extra leg room. This gives passengers a greater incentive to be on time and board first.

The benefits of this strategy are that people can easily identifying what seats are available and where they can sit. This hopefully minimizes seat and aisle interference because passengers take whatever seat is open. Passengers are able to self-manage the seating of the airplane reducing the airline's responsibility of processing. The potential for this strategy to decrease boarding time is still being determined and tested.

The cons of this strategy are that families or groups who want to sit together may not be able to if they are the last to board.

WilMA (Window, Middle, Aisle) Strategy:

The "WilMA" strategy stands for window, middle, and aisle. It involves passengers boarding the plane in that specific order. First of all, the window passengers board on either side of the aisle from the rear of the plane to the front. Then the middle passengers board the plane and finally those closest to the aisle.

The pros of this strategy revolve around seat and aisle interference. If done correctly and in the right order seat interference is completely eliminated. Aisle interference is also virtually eliminated because every passenger has time to stow luggage.

One downside of this strategy is that groups or families might initially be split up. Since they cannot board at the same time and there is assigned seating, they will end up sitting next to each other. After the window seat passengers board the plane and start to sit down the aisle is practically empty. There is a lull in the traffic down the aisle. This means the next middle group has to travel down the entire length of the aisle taking up valuable time.

New or Hybrid Strategies

These are some new strategies or hybrids of existing ones that we came up with. The first strategy involves dealing with carry-on baggage. What if passengers were not allowed any carry-on baggage? This would certainly speed up the boarding process because they would only have to walk down the aisle and get to their seat. Movement down the aisle would be faster because they would not be carrying luggage. Personal items like small backpacks and purses would be allowed. Much of the carry-on baggage passengers bring on the plane consists of clothing and other items that are unnecessary for the flight.

A hybrid strategy we thought of involves pairing people up. One person has a carry-on item and the other does not. In this way they are able to go down the aisle and get to their seat quickly. By spreading out the passengers with bags we reduce the amount of time people wait for a space.

Computer Simulation

Our computer simulation tracks the number of rows in the plane, the number of seats on either side of the aisle, the number of passengers, and the percentage of passengers who have carry-on luggage. The simulation also allows modification of the time required to pass over an already seated passenger and the time to stow carry-on luggage in the overhead bins. It was determined that the simulation would have only one aisle to simplify the model. A simulation was created because it expedites the collection of data. It was written in the Java programming language. For the full source-code see the appendix. This is especially true for simulations with variables that allow for randomness. With large numbers of people this randomness factor goes up exponentially. When the simulation is run, some of the passengers may have baggage and upon choosing to sit will need to put it away. This passenger is now blocking the aisle and the passenger behind them must wait to continue.

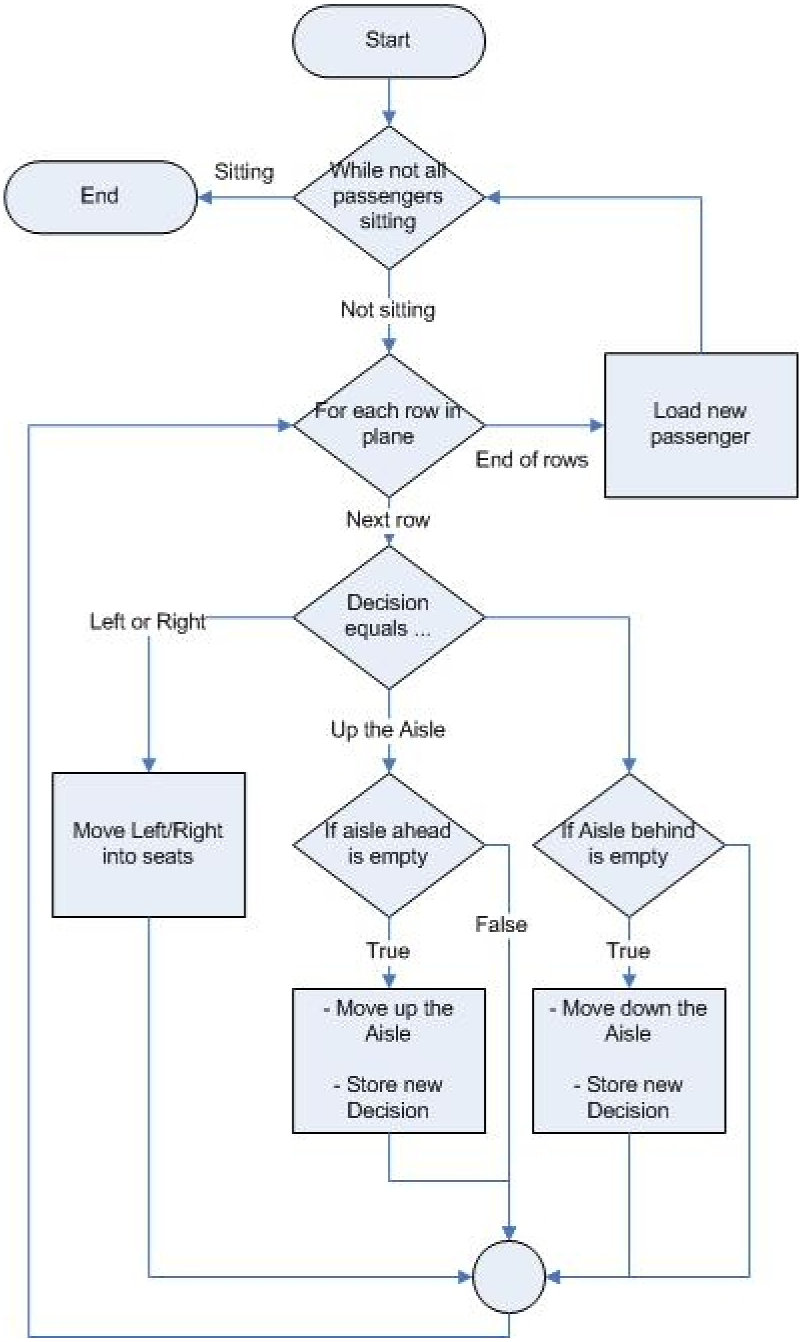


Figure One

Figure One shows the flow of each strategy in the computer simulation. This is a general representation of the three strategies. As the simulations steps through, any passengers in the aisle move according to their decision. If they move on down the aisle, the next intervals movement is decided and stored. Whenever the aisle in the first row is empty a new passenger is loaded onto the plane. This continues until all passengers are on the plane and sitting down. The difference in the code is in “store new *decision*” section of the flow chat.

In the random strategy simulation the first passenger will load on to the plane and from there *decide* to sit to the left, sit to the right, or continue down the aisle. If they want to sit and they have a bag, the passenger will block the aisle. When the passenger wants to sit they may have to move past another sitting passenger causing the time taken to increase. This is called seat interference. If the passenger has chosen to move farther down the aisle the process starts again. Due to all of these random factors, this was the most difficult strategy to implement.

In the “Back to Front” strategy the newly loaded line of passengers will *decide* to continue to the rear of the plane until they arrive at the farthest row with an empty seat. As before, if the passenger has baggage they will temporarily block the aisle. At this point they *decide* to sit down.

In the “WilMA” strategy the passengers step on to the plane and *decide* to continue down the aisle until the first one reaches the last aisle. At this point every passenger in the aisle *decides* to turn and sit on the side of the plane with the fewest number of passengers. In this strategy the longest delay in loading that can occur will be the storage of one carry-on bag.

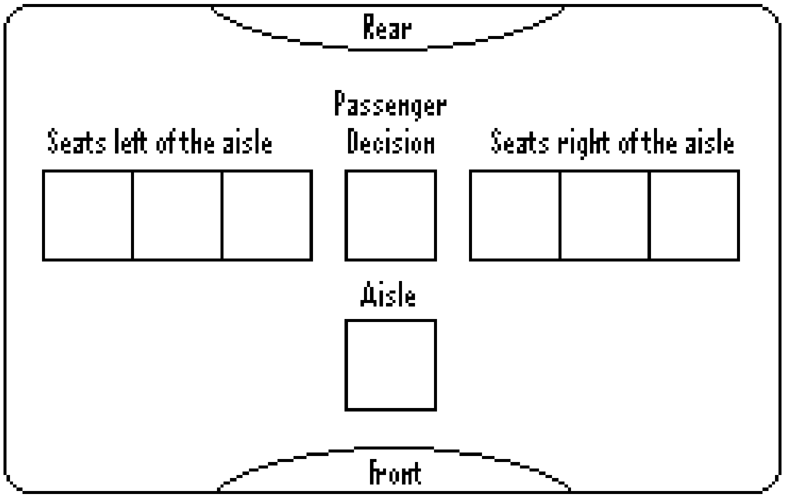
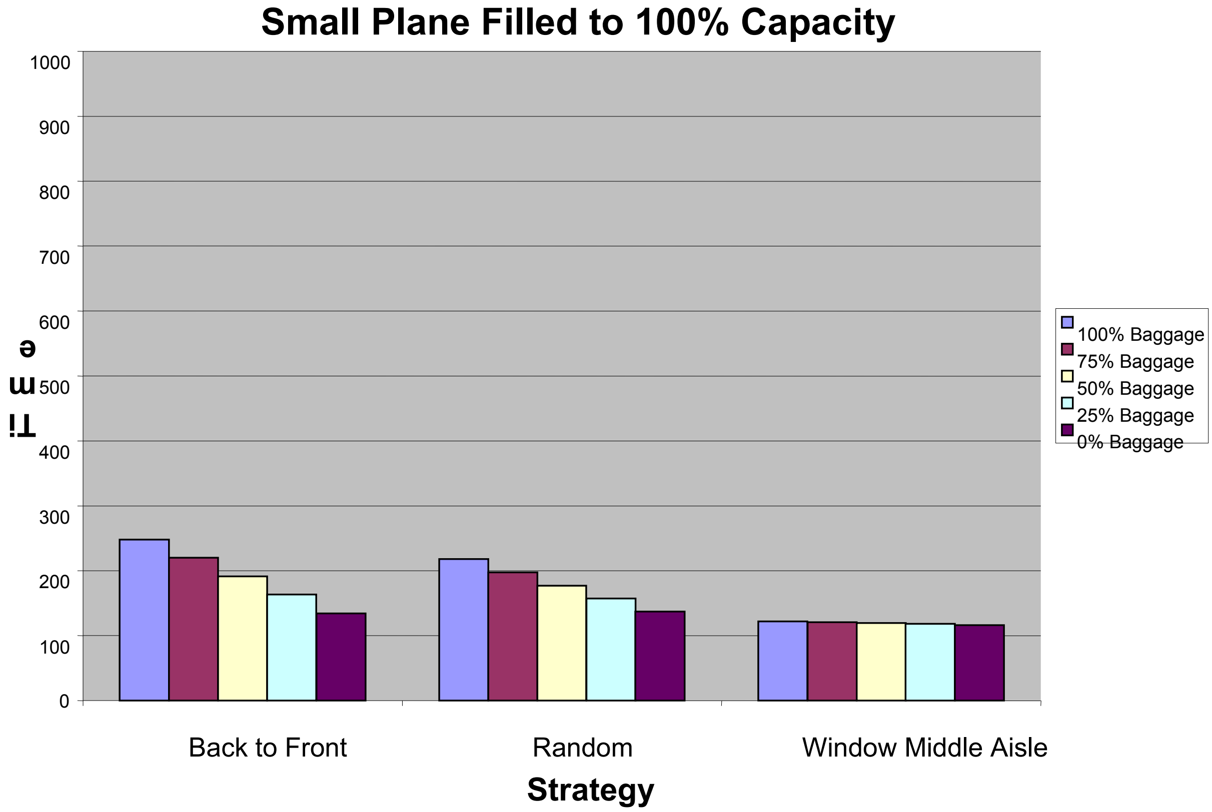


Figure Two

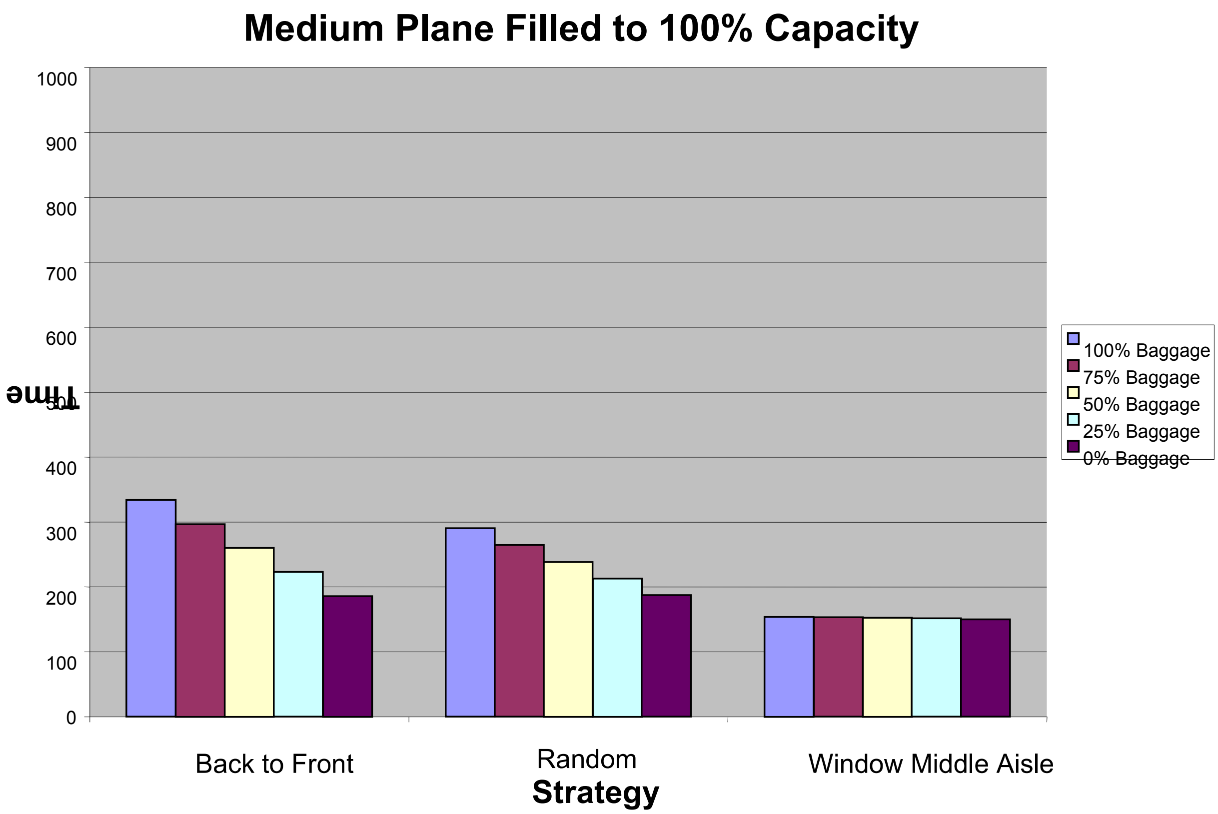
The time kept by the simulations is not in seconds but rather in intervals of time units. One time unit is the time it takes to get from one aisle row to the next aisle row or the time to move one seat in either direction. The actual computer data structure behind the simulation is made of custom objects called RowNodes. An example RowNode can be seen above in *Figure Two.* These RowNodes contain storage for the seats, the aisle in the row, and the current passenger's next decision. Each seat contains a numerical value indicating whether or not there is a passenger occupying the seat or another passenger moving down the row to sit. The aisle contains a numerical value indicating the presence of a passenger and if they have baggage. The passenger decision code keeps the next planned action of the passenger in the aisle. In order to allow for varying number of rows, each RowNode also contains a link to the next row in the plane.

Computer Simulation Results

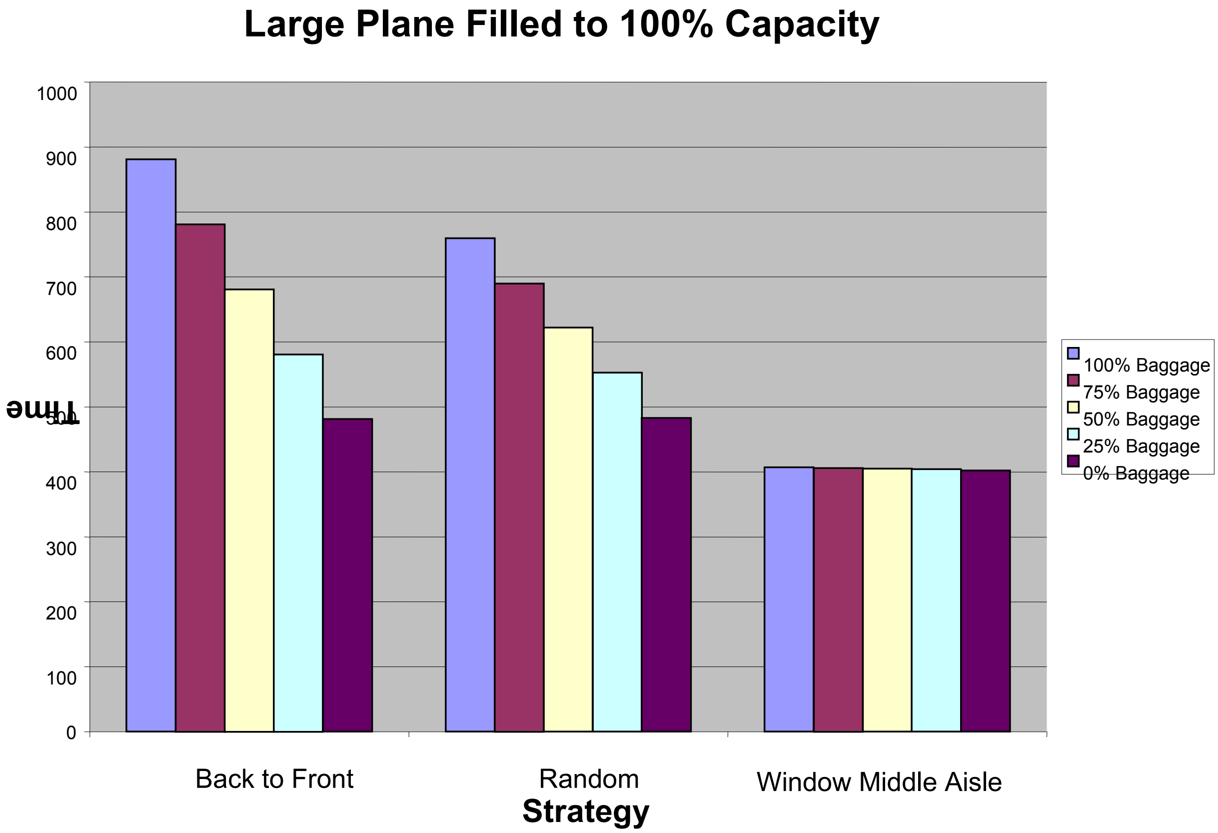
Based on the computer simulations run on small, medium, and large plane sizes the "WilMA" strategy was shown to be the most efficient. As the size of the plane increases the total time required to board the plane increases as well. This is to be expected since there are more people trying to get on the plane and they have to walk a long way.



The above graph shows how the carry-on baggage variable affects the load time under the different strategies. This is based on an airplane with a seating capacity for 114 passengers which is completely filled. As expected, the “Back to Front” and random strategies show that a decrease in baggage directly affects the amount of time required to board. The “WilMA” strategy was able to deal with varying amounts of baggage in an efficient manner. “WilMA” is almost completely unaffected by increased baggage amounts.



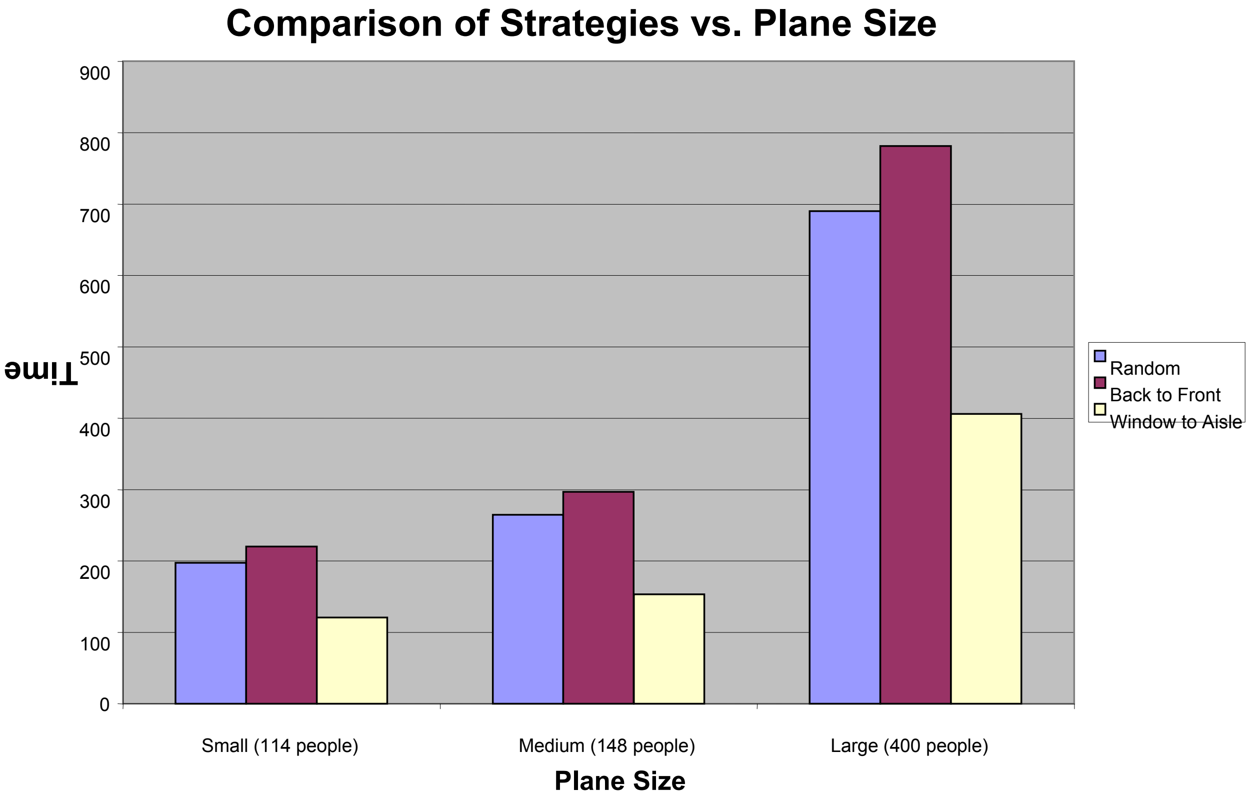
The above graph shows how the carry-on baggage variable affects the load time under the different strategies. This is based on an airplane with a seating capacity for 148 passengers which is completely filled. It is assumed that if a plane has two aisles it will take the same amount of time to load each half of the airplane. Running a simulation on a plane with the same number of rows but half the number of seats and passengers should return the expected result. Confirming our assumption, the "Back to Front" and random strategies show that a decrease in baggage directly affects the amount of time required to board. The "WilMA" strategy was again able to deal with varying amounts of baggage without much change in the time required to board.



By now we can see a trend in the "WilMA" strategy. The number of people is linearly related to the time it takes to board the passengers under the "WilMA" strategy.

$$Rows \bmod Passengers = 0 \tag{1}$$

Where a mod b, standing for the modulo operation, returns the number remaining after dividing b by a. If (1) is false, then there are passengers that will not be assigned to a full column of seats, and therefore have to walk to the back of the plane. In doing so, the time required to board the plane increases by a, the number of rows in the airplane.



The above graph details the comparison between planes of different sizes assuming every seat was filled and only 75% of the people had carry-on luggage. As you can see, the random and “Back to Front” strategies increased proportionally to the plane size. The “WilMA” strategy performed the best over the varying plane size. This is because the “Back to Front” and random strategies potentially require everyone to wait for the passengers to stow carry-on luggage. In “WilMA” every passenger stores their carry-on luggage at the same time thus reducing the total wait time due to stowing luggage. For example, in an airplane with four rows, “Back to Front” will require one extra time unit for each person if every passenger with a bag. In “WilMA” this is only one extra time unit for every four passengers with a bag. This makes “WilMA” an excellent choice for airlines not wanting to change their baggage policy. However, it must again be stressed that the “WilMA” strategy makes it harder to board groups such as families.

Efficiency comparison of each strategy

Strategies	**Time Ratios**
Back to Front / Random	1.12
Back to Front / WilMA	1.89
Random / WilMA	1.69

Figure Three

The random strategy is 12% more efficient than the "Back to Front" strategy. The "WilMA" strategy is 69% more efficient than the random strategy and 89% more efficient than the "Back to Front" strategy. This again shows the benefits of the "WilMA" strategy in terms of time efficiency.

Psychological Considerations and Incentives

Stepping away from the mathematical perspective on the problem, there are a variety of psychological factors that can influence how long it takes to board an aircraft. Cultural differences could potentially play a role. "Willy-Pierre Dupont… watched some 560 passengers on a Japan Airlines domestic flight in Japan disembark in six minutes flat. The same turnaround in the U.S. or Europe could take as long as an hour and a half." (Zamiska 2005). Could people who are more polite and courteous actually make the total time for the group lower? Could this be related to human cooperation? This is certainly an area that requires more research.

What if the airlines could provide incentives for people to board the plane quickly? One possible solution would be to provide monetary incentives based on how long the entire group takes to board the plane. This would entice people to cooperate and be helpful towards others for the good of the group. The cost of the airline paying people for boarding a plane would be far lower than the money they would save because of the extra time. The airline would have to decide whether they want to increase people's ticket price based on the time (positive punishment) or give them a rebate (positive reinforcement). With negative punishment, the airline wants to prevent people from boarding slowly so they increase the price. With positive reinforcement, the airline rewards people for boarding quickly so they give them a rebate. The downside to this strategy is that people might become more aggressive towards others if they are slow. This would make things worse not only for the well-being and happiness of the passengers but also the time it takes for the people to board.

Another possible incentive is to charge people for carry-on luggage. Personal items like a small backpack or a purse would not be included but large items like suitcases would require an additional fee. From personal experience, it seems that stowing carry-on luggage takes up a tremendous amount of time. It takes too long in a full flight for an individual to cram a piece of luggage in an overhead bin that clearly does not fit. This incentive is better than getting rid of carry-on luggage completely because people still have the option if they so choose.

A similar incentive involving trying to limit carry-on luggage involves letting people with no carry-ons get on first. Then the people with only one carry-on piece can get on, then two, and so on. This would have to be strictly enforced by the attendants working at the gate. It is questionable whether this strategy would work because it seems the entire reason why people want to get on the plane so badly in the first place is so they can get a space in the overhead bins. Surveys would be beneficial in determining why people want to get on the plane so quickly. It is obvious that people want to get off the plane. Being cooped up in a small environment unable to move for hours on end is not exactly the most pleasant situation.

Deboarding from the airplane is the simplest thing to explain from a psychological point of view. After sitting in an aversive environment for a long time people just want to get out of the plane. They want to get to their next flight, see relatives, or get home. There really is not much airlines can do in terms of optimizing the deboarding process other than adding more doors to get out. The personal drive and enthusiasm is already there.

Weaknesses of the Computer Simulation

The weaknesses of the computer simulation involve using too many assumptions. This was for simplicity sake and certainly helped make the model easy to understand and implement but in the real world there are millions of potential variables. Based on personal experience and reading online we chose the most prevalent and applicable variables.

For example, we did not account for seat interference where passengers have to move back out into the aisle. A time delay was included but it was assumed that passengers would be able to move through the row to their own seat without making already seated passengers stand in the aisle.

To account for planes with two aisles it was assumed that the two aisles would be utilized at the same time. Because of this, a plane with two aisles can be modeled with half the number of seats in each row and only one aisle.

Another variable we simplified greatly was the grid system for the aisle and seats. If there is a person in the aisle then no passenger is able to move past. This is slightly unrealistic for real-life situations because passengers might be able to move into the row for a minute to let people by.

Future Work

One way our computer simulation could be strengthened is to use surveys and gather additional detailed information on each of the variables. This would allow for more accurate predictions and simulation runs. Adding more variables to get rid of assumptions or making existing variables more specific would help. This makes the model more realistic. Does carry-on luggage slow people down as they move through the aisle? If so, how much does it affect boarding time? How do the conditions outside the airplane affect the process? Variables pertaining to the gate, the attendants checking tickets, and even random bag searches probably have a small effect.

One variable that we initially intended to include was groups and other variations of passengers. Groups were not included because of complexity issues. Families and other groups that often get seats next to one another often board together. Do they take more or less time than a single passenger to board? A parent might carry their child's luggage and thus a slowdown occurs. Passengers in wheelchairs, the elderly, or those who need special assistance might require additional time or help.

A variable we would like to expand upon is dealing with seat interference. If a passenger has to get up and move into the aisle to let another passenger in this takes up time and blocks the aisle.

One future topic involves viewing the problem from an economical standpoint. Normally, airlines overbook and sell more tickets than they actually can provide. This is because a certain percentage of people do not show up. While this attempts to maximize profit, the hassles involved with giving rebates when there are too many people can be disadvantageous. If the airline is able to provide enough incentive for people to choose a different flight they still have to deal with finding more seats for the next flight. In this way it can become self-propagating. Would it be more cost-efficient for airlines to under book their flights in order to save time boarding passengers?

To do this, the airline needs to calculate how much they lose for each ticket they do not sell. This is then compared to the money earned because the time saved allows them to run more flights. The calculations involved in comparing this center around finding derivatives. This cost-benefit analysis would add another dimension to any future models.

The airline also has to take into account passenger morale. If faster boarding time yields faster travel times then the airline customers will be more apt to choose them for future flights. The increased efficiency can be used not only to save money but as a customer service and advertising tool. Who knows, could happier customers lead to faster boarding times?

Conclusion

While the simulated "WilMA" strategy was the most efficient of the three strategies it is unclear whether this will work perfectly in the real world. The preprocessing by gate agents and flight crews may be too much for airlines to deal with. Any random variations by passengers could throw the entire strategy into disarray. It is certainly clear that the pure "Back to Front" strategy is not the best. The random strategy seems to work well and caters to the "randomness" factor that passengers possess, while the "WilMA" strategy is the most efficient in a simulated, controlled environment. There are many directions and angles that these strategies could take. By removing assumptions and testing future models with more robust variables, real world validity can be established. The potential for airlines to save millions of dollars through decreased travel time warrants continued research and discussion on this topic.

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