An Analysis and Design of Simulation Modelling for Airplane Passenger Boarding Strategy during Normal and New Normal Periods

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Abstract: Boarding process is the main activity that became the key efficiency in each turnaround process on the airport. The successful in achieving time efficiency will give some benefit to all parties, including airlines, airport management and passengers, especially related to business sustainability, operational and customer satisfaction reasons. The objective of the research is to design an effective model for passenger boarding strategy that focus on airplane with a 180-seat configuration, in scenarios for both normal and new normal periods using agent-based simulation in NetLogo 6.1.1. The simulation output was processed using descriptive and sensitivity analysis and also Chi Square test of independence methods. The simulation results show that Wave strategy which is implemented through the seat-assignment and group-assignment has successfully demonstrated its effectiveness and gives an alternative to be applied by the airlines, for both in normal and new normal periods. By comparing the average boarding time with scenarios in the normal period (load factor 100%) and the new normal period (load factor 66.7%), it is found that the average boarding time by applying 1.0 meter of social distancing is about 78.21%, while for 1.5 meters about 116.06% and for 2.0 meters about 138.29%. Furthermore, by using the Chi Square test of independence analysis, it can be seen that the application of social distancing is highly correlated to the effectiveness boarding strategy.
Keywords: Agent-based simulation, Effective boarding strategy, Normal and new normal periods,Social distancing, Wave strategy

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1. Introduction

The airline industry is a capital-intensive business, which is costly to operate in effective manner. In fact, the airline industry provides a vital service, but the profit margins are slim even in their best season. This happens because of the high operational costs that must be managed by the airline. In addition, the airline industry is also vulnerable to various exogenous events such as political instability, economic recession, terrorism, natural disasters and pandemics, which can drastically affect their operations and market demands (**Kumar & Fernandez, 2019**).

The process of handling airplane on the ground, or better known as turnaround, is a fundamental part of commercial airlines operations, which describes the airplane transition cycle from landing to take off on the next flight. Here, the length of time spent in each airplane turnaround time becomes a metric used to measure the efficiency of an airline's operational side and is the basis for business sustainability, especially if it is related to the amount of operational costs that must be incurred by the company. In this case, achieving time efficiency in activities related to turnaround will directly reduce turnaround time, so that it will have a significant saving impact on the airline. In previous studies, it was estimated that the cost of parking an airplane per minute ranges from $ 30 to $ 77 **(Nyquist & McFadden, 2008; Steiner & Philipp, 2009)** and it can even higher up to $ 250(**Horstmeier & De Haan, 2001**). Therefore, the airlines will consider every effort to minimize unproductive time while the airplane is on the ground.

Although several activities in the turnaround process can be carried out simultaneously so that the process becomes efficient, statistical results show that the passenger boarding process is the most time-consuming stage, reaching more than 60% of the total turnaround time (**Giitsidis & Sirakoulis, 2016**). The time duration of the boarding process is influenced by many factors such as airplane seats configuration, boarding strategy, load factor, queueing order, passenger movement velocity, amount of carry-on luggage, interferences, and so on. Here, the boarding process is the main activity that become the key of time efficiency in each turnaround process on the airport. The airlines company need to pay attention to the boarding process because they have limited control over passengers and it is the most difficult factor to control in the entire turnaround process (**Jafer & Mi, 2017; Soolaki et al., 2012; Steiner & Philipp, 2009**).

For airlines company, the Covid-19 pandemic situation has dealt a blow to their business existence. During large-scale social restrictions or lockdowns, practically no airlines could operate and all airplane had to be grounded for several months. After the number of the spread of Covid-19 virus has decreased, the government can relax the social restrictions and allow airlines to resume operations. However, at a certain time after the Covid-19 pandemic, the public is required to continue in applying strict health protocols in their daily activities and make it as a new habit so that it is known as new normal period. Among the health protocols implemented are the obligation to wear a mask on each passenger, a limit occupancy to 67% of the total airplane seat capacity, and the implementation of social distancing during the boarding process. The World Health Organization also emphasized the importance of implementing a minimum distance of 1 meter between individuals as one of the main steps that must be taken to reduce the impact of the spread of the Covid-19 virus (**WHO, 2019**), while IATA provides guidance on ideal distances ranging from 1-2 meters (**IATA, 2020b**). Here, the public compliance with social distancing policies is part of controlling this pandemic(**Yanti et al., 2020**). On the other hand, a study by **Barnett & Fleming (2020)**provides clues that by emptying the seats in the middle, the possibility of spreading the Covid-19 virus among passengers sitting on the plane will be halved.

The agreed global actions in the recovery of the aviation industry during the new normal period will significantly change operational parameters, all of which can in-crease turnaround times, thereby reducing overall airplane utilization (**IATA, 2020a**). This is of course become a major issue for the airlines, especially if they see that the number of passenger seats that can be sold is not maximal. In fact, airlines break-even is at a load factor of 77% on average (**IATA, 2020c**). Thus, airlines must reconsider the economic side of their business by looking at relatively high operational costs such as fuel cost, personal expenses, airport and air traffic control (ATC) facilities usage cost, ground-handling cost, airplane technical maintenance cost and other operational cost **(Renold et al., 2019**).

2.Significance of The Study

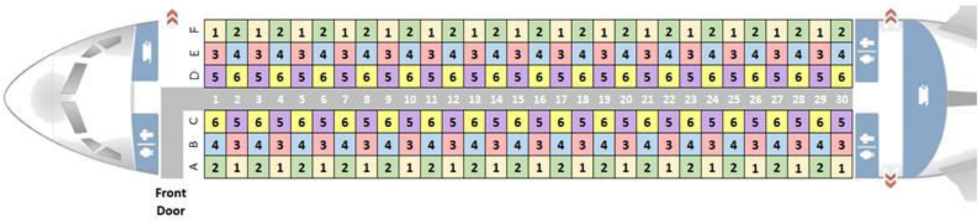
The existence of the aviation industry, either directly or indirectly, has facilitated tourism, trade and economic growth so that it has become the main key to the emergence of globalization in various other industrial sectors. Therefore, even though the aviation industry is vulnerable to various exogenous events such as the Covid-19 pandemic which is currently happening in most countries and affecting their operations and market demand, this business that has a vital service must continue to run.

The applying of social distancing, especially during the new normal period of post Covid-19 pandemic is intended so that airplane passengers can avoid the possibility of exposure to the Covid-19 virus when they want to travel using air transportation services. The greater the distance applied, the smaller the health risks faced by airplane passengers. However, the applying of the distance between individual should also be adjusted to the calculation of the economic business that must be maintained by the airline, where the greater the applying distance between individuals, the longer the boarding time will be. This makes the efficiency of the airline's operations will be difficult to realize.Since the passenger boarding is the most time-consuming stage in airplane turnaround process, then this research was carried out to find an alternative boarding strategy that effective to be applied by the airlines, both normal and new normal periods.Here, the use of simulation can produce various alternative improvements that will be more difficult to obtain if only using direct experiments on field. From the alternatives presented, a system comparison can be obtained to determine which solution is the best.

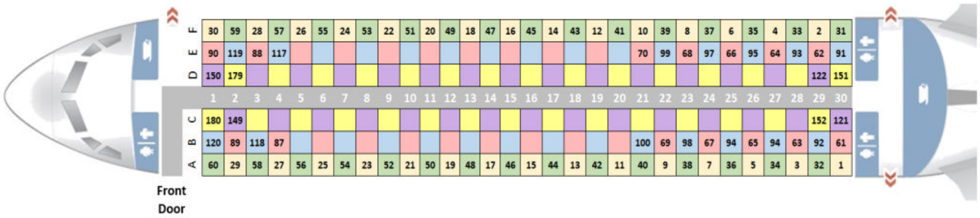
In addition to the six other classical boarding strategies whose literatures already discuss in other similar studies, the authors propose the new method for airplane passenger boarding through single door via jet bridge that will be simulated to test its effectiveness with scenarios during the normal and new normal periods. The new boarding strategy proposed by the authors is called the "Wave" strategy which will be simulated through seat-assignment and group-assignment approaches.

In the Wave-group (WG) strategy, the passengers who enter the plane will be divided into 6 groups and fill the seats on the left and right side of aisle with alternating rows starting from the window, middle and aisle positions. The way of filling the seats across the left and right side of the aisle by spacing one seat-row on each side forms a design that visualizes the 'wave frequency' so it is called the ‘Wave’ strategy. Furthermore, the Wave-group (WG) strategy also has its own uniqueness because the filling of passengers in each seat-row both on the left and right side of the aisle forms an alternating odd-even configuration as shown in Figure 1a.

Besides implemented in a group-assignment, the Wave strategy can also be implemented through the seat-assignment approach as shown in Figure 1b. In the Wave-seat (WS) strategy, passengers enter the plane starting from the passenger with the seat number in the rearmost row followed by another passenger who sit in the row in front of him/her but across the aisle with adaptable seat-row spacing. This adaptable can be applied as long as the seat-row spacing number is the same as shown in Figure 2. Moreover, this adaptable seat-row spacing is an advantage and flexibility of this Wave-seat (WS) strategy and can be applied during the new normal period as an adjustment and balancer to the implementation of social distancing.In this case, when the airline implements 1.0 meter of social distancing, the Wave-seat (WS) strategy balances it by using ‘additional 1 seat-row spacing (s)’ between passengers. Likewise, when implementing 1.5 and 2.0 meters of social distancing, the Wave-seat (WS) strategy adjusts it to the additional spacing of 2 and 3 seat-row (s) between passengers.



(a)



(b)

Figure 1. Proposed Wave method as the novelty of airplane boarding strategy
(a) Wave-group strategy (b) Wave-seat strategy

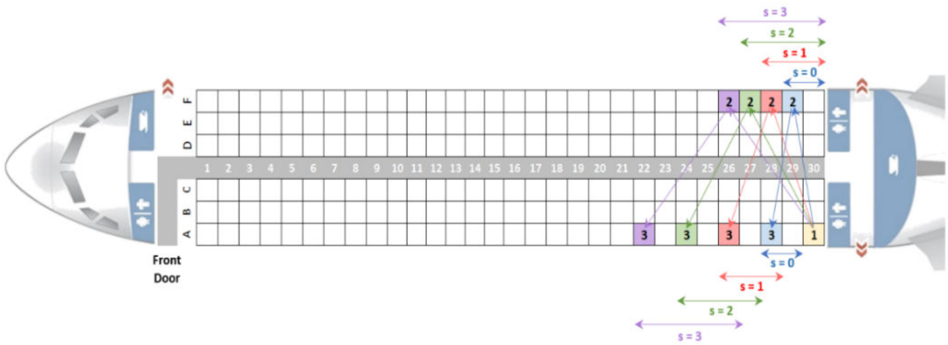


Figure 2. An adaptable seat-row spacingin Wave-seat strategy

By design, the proposed 'Wave' strategy provides enough space for passengers to store their belongings simultaneously into the overhead-bin so that it is expected to reduce the problem of aisle interference and eliminate seat interference which causes boarding time to be longer. Furthermore, the innovation of the ‘Wave’ strategy proposed by the authors look quite ideal to be applied during the new normal period of post Covid-19 pandemic because they provide sufficient space between passengers to minimize the possibility of physical contact between them.

Here, the significance of this research is to introduce alternative boarding strategies that can be implemented in normal and new normal periods by the airlines, with the consistency in achieving an effective boarding time. The proposed strategies will be compared to six other classical boarding strategies that have been discussed in previous literaturesand provide graph of boarding time patterns as evidence of the consistency about its effectiveness.

3.Review of Related Studies

Based on literatures, there are various methods used to decide on the effective and efficient boarding strategy, including: cellular automata(**Giitsidis & Sirakoulis, 2016; Qiang et al., 2018; Schultz, 2018a; Schultz & Soolaki, 2021**), discrete event simulation(**Van Den Briel et al., 2005; Zeineddine, 2017**), cellular discrete event specification(**Jafer & Mi, 2017**), agent-based simulation(**Cotfas et al., 2020; Delcea et al., 2018; Iyigunlu et al., 2014; Milne et al., 2020**), field experimental test(**Qiang et al., 2017; Schultz, 2018b**), mixed integer programming modelling(**Salari et al., 2020**), Markov Chain Monte Carlo optimization algorithm (**Steffen, 2008**) and so on.

In this discussion, the proposed strategy is compared with six other boarding strategies, including: Steffen, Random, Back-to-front, Rotating-zone, Outside-in and Reverse-pyramid. The rule of each strategy is described as follows:

- Steffen (SF) strategy
  The Steffen strategy was developed on the premise that one of the main factors causing delays during the boarding process is the time it takes for passengers to put their belongings into the overhead-bin. Using a Markov Chain Monte Carlo optimization algorithm and computer simulation, **Steffen (2008)** divides the incoming passengers into a strictly defined sequence starting on the side of the window seat from the back to the front, followed by the middle and last part on the aisle side. This is intended to provide enough space for passengers to put their belongings simultaneously so that the duration of boarding time can be reduced.
- Random (RD) strategy
  In the Random strategy, passengers get into the airplane randomly and there is no need for special instructions from the airlines crew. This strategy is the simplest approach and does not require a lot of effort in its implementation so that it becomes the basic foundation in seeing the reality of the actual boarding time. This strategy is generally applied by airlines that have not made certain efforts to make the passenger boarding process more effective and efficient.
- Back-to-front (BF) strategy
  In the Back-to-front strategy, passengers are divided into several groups and enter the plane according to the call order of the group number starting from the back seat then continuing to the front seat. The idea of this strategy is to minimize the aisle interference by reducing the length of queues in the aisle where each passenger tries to get to his / her own seat as quickly as possible. This method is considered as the most logical boarding strategy in a random order. Moreover, the facts on field prove the widespread use of this strategy by the airlines.
- Rotating-zone (RZ) strategy
  In the Rotating zone strategy, passengers who enter the plane are divided into several groups where the first group fills the front seats, followed by the second group fills the rear seats. Then proceed with the third group filling the seats be-hind the first group, followed by the fourth group filling the seats in front of the second group, and so on. The advantage of this strategy is that each group occupying the passenger seats on the front and rear sides will not interfere with each other.
- Outside-in (OI) strategy
  To minimize seat interference, the Outside-in strategy proposes that airplane passengers be divided into three groups based on their seat position, whether near a window, in the middle or next to the aisle. Passengers sitting near the windows will enter the plane first, followed by passengers sitting in the middle and ending by passengers sitting near the aisle. Through this pattern, this strategy is also known as Window-Middle-Aisle or WILMA. This strategy is intended to eliminate seat interference so as to reduce waiting time for aisle interference.
- Reverse-pyramid (RP) strategy
  The Reverse Pyramid Strategy was introduced by **Van Den Briel et al. (2005)**. It is a hybrid strategy that combines the concepts of Back-to-front and Outside-in strategies. In this strategy, passengers board the plane in a way like the letter V where passengers who sit near the rear and middle windows will enter the plane first, followed by the rear aisle and front window. The development of this strategy is also intended to eliminate seat interference so as to minimize the length of waiting time for aisle interference, but in a more complex way.

Most of methods have been discussed for cases where the boarding process is applied just in the normal period or in the new normal period only, and relatively few discuss them both in the normal and the new normal periods and make comparisons of their effectiveness.

3.1Agent-based Modelling in NetLogo

A technique that can be used to model and describe various processes, phenomena, and situations is agent-based modelling (ABM). ABM is a micro-scale model that simulates the simultaneous operation and interaction of several agents in an effort to recreate and predict the emergence of complex phenomena so that they can represent various realities in the field(**Wilensky & Rand, 2015**)and are ideal for implementation in research on passenger boarding strategies.

There are several tools used in ABM simulation, one of which is NetLogo 6.1.1. NetLogo 6.1.1 provides a comprehensive interface, which can visualize the agent's actions in real-time, accompanied by an integrated graphing function and a fairly good execution speed. Furthermore, the agents in the NetLogo 6.1.1 simulation are divided into four categories:

- Turtles: agents who can move in the world.
- Patches: grid-shaped agents that have a unit area where turtles can move.
- Links: agents that connect one turtle to another if there is a relationship between them.
- Observer: someone who gives instructions to manipulate all agents in the world. In this case, the world is a two-dimensional area composed of patches.

Visually, the simulation made using NetLogo 6.1.1 is two-dimensional as shown in Figure 3, so it is hoped that it can be easily understood by all parties, including those who are not experts. To get output that is quite representative and close to the reality on field, an adaptation is carried out to the formula based on data reference comes from the field experiment tests on the previous studies. By using this approach, it is hoped that the resulting output will not only be a value on paper.

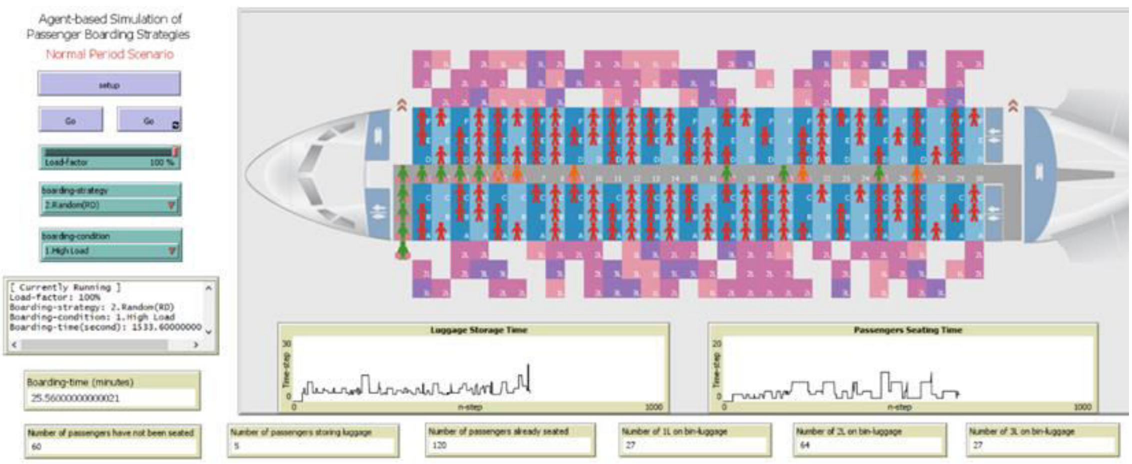


Figure 3. An example of agent-based simulation in NetLogo 6.1.1 for passengers boarding strategy

3.2 Passengers Movement Model

Inprevious studies, **Van Landeghem & Beuselinck (2002)**and**Qiang et al. (2014)** used a triangular distribution to calculate the time duration required for passengers to pass through each seat row and obtained a modus value of 2.4 seconds. Therefore, each time-step in this simulation will also correlate with 2.4 seconds of the absolute boarding time. Furthermore, for the passenger movement model, each agent is designed with the initial position at the left front door and enters the airplane with an interval of 7 seconds. The agents then walk on the aisle with velocity ranging between 0 and 1 patch per tick. In this case, tick is the unit of time used in NetLogo.

3.3 Passengers Load Factor

The passenger load factor is one of the parameters used as important driver in determining the airlines' financial performance. Based on a sample of 122 airlines, on average, airlines break even at a load factor of 77%(**IATA, 2020c**). In this regard, this research will simulate several boarding strategies in a normal period scenario with a load factor of 100%, 80%, 66.7%, 60% and 40%, then will analyse their effectiveness based on the resulting average boarding time.

During the new normal period of post Covid-19 pandemic, the maximum passenger load factor is limited to the level of 66.7%. In this case, the most common scenario carried out by airlines is to empty the middle seat in each row (seat B and E). Therefore, in the new normal period scenario, all of the tested strategies will also experience emptying of the middle seat in each row with a similar boarding layout.

3.4 Bin Occupancy Model

In a normal period, it is assumed that the airline allows the passengers to carry their belonging to the cabin ranges from 1 to 3 with a percentage distribution as shown in Table 1. This percentage distribution correlates with previous study by **Qiang et al. (2014)**which seemed ideal to apply. On airlines where all seats are allocated to economy class only, passengers generally avoid storing their luggage in the baggage. This is due to the policy of applying paid baggage in several low-cost carrier and the risk in the content burglary of passenger belongings on the baggage(**Musofa et al., 2021**).

Meanwhile in a new normal period, it is assumed that the airline still allows passengers to carry their belongings to the cabin with a maximum of 3 items. The reason is, with the passenger load factor only 66.7%, there will be enough space in the overhead-bin. In addition, by allowing passengers to keep carrying a maximum of 3 items, it can reduce the storage of passenger's belongings in the baggage so that the possibility crowds of passengers at the baggage claim area on the arrival terminal can be minimized.

Here, the distribution of passenger's carry-on luggage on the overhead-bin is assumed as below:

- 1L with patch color in pink: passengers store a suitcase with a size of 20 inches.
- 2L with patch color in magenta: passengers store a suitcase with a size of 20 inches and a goodie-bag.
- 3L with patch color in violet: passengers store a suitcase with a size of 20 inches, a goodie-bag and a laptop bag.

Tabel 1. Luggage distribution under different load condition

Boarding in different load condition	Percentage distribution		
	1L	2L	3L
High load	20%	60%	20%
Normal load	60%	30%	10%
Low load	80%	10%	10%

The time required for each passenger to store their belongings to the overhead-bin (t_i^{store}) is calculated using Equation 1 as proposed by **Qiang et al. (2014)**and correlated with the time-step in the simulation.

$$t_i^{\text{store}} = 1.5 + \frac{10N_i}{[(9+1)-(N_e+N_i)]} \quad , \quad N_i \geq 1 \tag{1}$$

where:

N_e= The number of luggage that already existing in the overhead-bin
N_i = The number of luggage carried by the passengers

3.5 Passengers Seating Model

In the boarding process, delays can occur due to interferences. There are two types of interferences, namely aisle interference and seat interference. Aisle interference occurs when a passenger whose storing his/her belongings to the overhead-bin blocks access to other passengers who want to go to their seat.

On the other hand, the seat interference occurs when a passenger has to wait for one or two other passengers who are already seated in the same row to clear his/her way to the assigned seat. In general, there are four types of seat interference as shown in Figure 4. From the field trial performed by **Schultz (2018b)**, the type-1 seat interference will block the aisle with a time duration of 20 - 26 seconds, while type-2 seat interference ranges from 10 - 14 seconds. Furthermore, for type-3 and type-4 seat interferences, the field study performed by **Qiang et al. (2017)**reported a time duration about 7 seconds.

In scenario during the normal period, to make the time duration for each type of seat interference closer to the results of the field trials, an adaptation was made to the formula proposed by **Qiang et al. (2014, 2018).** Equation 2show in calculating the time required for passengers to move from the aisle to their respective seat.

$$t_i^{\text{seat}} = t_p\,(1 + 2M_i) + t_d\,, \quad M_i \geq 1 \tag{2}$$

where:

t_i^{seat}= The total time for seating (rounded to the nearest integer)
t_p = The time step used to get from the seat into the aisle or back (1,5 time-steps)
M_i = The number of seat interference
t_d =Delay time occurs when the passenger sits in his/her seat (1 time-step)

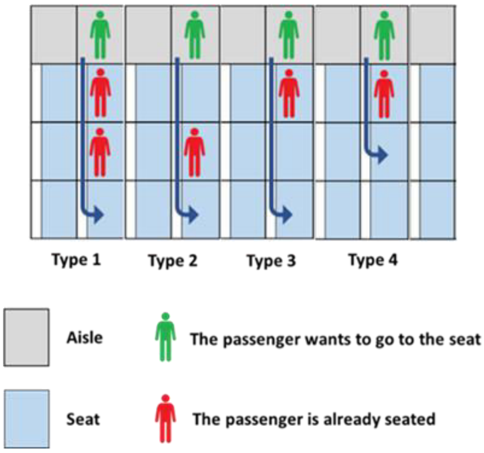


Figure 4. Four types of seat interference
Adapted from**Delcea et al. (2018)**

Here, by using Equation 2, the simulation will obtain the time duration of each type of seat interference as shown in Table 2.

Table 2. Seating time under different types of seat interference

Type of seat interference	Seating time	
	Time-step	**Time conversion (second)**
Type 1	9	22
Type 2	6	14
Type 3	3	7
Type 4	3	7

Meanwhile, if there is no seat interference, the time required for passengers to shift from the aisle to their seats (t_i^{seat}) will follow the number of steps from each passenger as shown in Table 3.

Table 3. Seating time when there is no seat interference

Passengers seat position	Seating time	
	Time-step	**Time conversion (second)**
Near the window	3	7
In the middle	2	5
Near the aisle	1	2

In new normal period, there will only be Type-3 of seat interference since the middle seats must be vacated. However, the length of time to clear the seat interference will not be the same as on the normal period, because passengers who are already seated and have to stand up to give seat access to other passengers also need to apply social distancing protocol. Therefore, in this study it is assumed that the time needed to solve the Type-3 of seat interference in the new normal period is around 12 – 14 seconds, where the time is close to the Type-2 of seat interference.

3.6 Social Distancing Model During the Boarding Process

In our simulation, the implementation of social distancing protocol during the boarding process in the new normal period is carried out by providing distances between passengers in ranging from 1.0 meter, 1.5 meters and 2.0 meters. Since 1 patch equal 0.8 meter and to pass through each seat-row / patch obtained a modus value of 2.4 seconds, then:

- 1.0 meter = 1.25 patches (rounded to the nearest integer)
- 1.5 meters = 1.88 patches (rounded to the nearest integer)
- 2.0 meters = 2.50 patches (rounded to the nearest integer)

4.Objectives of the Study

- To design and introduce an alternative model for passenger boarding strategy that focus on airplane with a 180-seat configuration, in scenarios for both normal and new normal periods using agent-based simulation in NetLogo.
- To determinethe most effective boarding strategy that can be applied by the airlines for both in normal and new normal periods.
- To get output that is quite representative and close to the reality on field by using reference dataderive from the field experiment tests on the previous studies to the formulas that are considered the most appropriate. By using this approach, it is hoped that the resulting output will not only be a value on paper.
- To measure the percentage of gaps that occur in boarding process by comparing the resulting of average boarding time during the normal and new normal periods.
- To determine the effect of social distancing to the effectiveness boarding strategies.

5.Hypotheses of the Study

- Until now, Steffen (SF) strategy is considered as the strategy with the fastest boarding time completionwhile the Back-to-front (BF) strategy is the slowest.However, the boarding strategy with the seat-assignment and group assignment approaches should not be compared because they both have different concept, especially in terms of preparation before the boarding process.
- Reverse-pyramid (RP) strategy is considered as the strategy with the fastest boarding time completion on the group assignment approach.
- Factors that greatly affect the speed of boarding time are the process of storing passenger belongings to the overhead-bin and the passengers shifting process from the aisle to their respective seats.
- The implementation of social distancing protocol during the new normal period should not make the boarding process exceed the duration of the boarding time during the normal period with a load factor of 100%.
- The implementation of social distancing protocol during the boarding process will make significant affect to the effectiveness boarding strategy.

6.Population and Samples

In this research, for each boarding strategy simulations, 300 data samples will be taken under three different load conditions, namely high-load, normal-load and low-load. For the normal period scenario, 12,000 samples were taken from the simulation, consisting of five types of passenger load factor, including: 100%, 80%, 66,7%, 60% and 40%. Meanwhile for the new normal period scenario, 7,200 samples were taken from simulation, consisting of three types of social distancing that were applied, including: 1.0 meter, 1.5 meters, and 2.0 meters.

Here, the simulation model is made with limitations as follows:

- The simulation focuses on airplane with a configuration of 180 seats, where all seats are allocated for economy class only and the boarding process uses a jet-bridge.
- The simulation does not consider the profile and anthropometry of passengers such as gender, age, body size and weight.
- The simulation does not consider passengers traveling together in group.
- The simulation does not consider boarding priority for passengers with disabilities, passengers carrying small children and or the elderly, and pregnant women.
- The simulation does not consider boarding priority for passengers registered in the loyalty program.

6.1.Statistical Techniques Used in the Present Study

Here, the data obtained from the simulation output will be further processed using several analytical methods, namely descriptive and sensitivity analysis, as well as the Chi Square test of independence. The descriptive analysis is the statistic used in analyzing data by describing the data that has been collected. The collected data will be processed and produce statistical measures such as frequency, data concentration, data distribution, trend of a data set and others. In addition, to make data easier to read and understand, data can be summarized in tabulated form or presented in graphs, diagrams and histogram.

Sensitivity analysis is a technique used to determine how differences in the value of an independent variable affect the particular dependent variable based on a given set of assumptions. This technique is used within certain limits depending on one or more input variables, such as the selected boarding strategy, passenger walking velocity in aisle, amount of carry-on luggage and so on, which of course will affect the overall boarding time. The recommended effective boarding strategy is obtained if the boarding strategy being tested has the highest frequency distribution of minimum boarding timeof the entire simulation iterations.

The Chi Square test of independence which also known as Pearson Chi Square can be used to analyse the frequencies of two variables with multiple categories to determine whether the two variables are independent or have a significant relationship. Thus, the information about the effect of social distancing to the effectiveness boarding strategy will be obtained through a comparison between the Chi Square observations ($\chi^2_{compute}$) and Chi Squarecritical value ($\chi^2_{\alpha;df}$),with level of significant (α) = 0.05 and the previous defined hypothesis as follows:

- H_0 : The implementation of social distancing does not affect the effectiveness boarding strategy.
- H_1: The implementation of social distancing affects the effectiveness boarding strategy.

In this case, the decision is made based on one of the following results:

- Accept H_0 and reject H_1 → if $\chi^2_{compute} < \chi^2_{\alpha;df}$
- Reject $H_0$and accept H_1 → if$\chi^2_{compute} > \chi^2_{\alpha;df}$

6.2.Data Analysis and Interpretation

The average boarding time is a very important evaluation criterion in assessing the effectiveness of airplane passenger boarding strategy. The implementation of different strategies can result in a faster or slower boarding time on airplane with a similar model and configuration of seat numbers but of course it depends on many factors such as airplane seats configuration, passenger load factor, queueing order, passenger movement velocity, amount of carry-on luggage, interferences, and so on.

6.2.1. The Analysis of Passengers Boarding Strategies during the Normal Period

Airplane with load factor 100% can be the main references in determining the effectiveness boarding strategy chosen by the airlines, so that the data obtained later can be used in making assumptions and calculation bases for different situation.In the normal period scenario, the average boarding times and frequency distribution achieved by the eight boarding strategies with a load factor of 100% (180 passengers) can be seen in Figure 6, while the boarding time pattern based on the sequence in which passengers enter the airplane can be seen in Figure 5.

Here, the boarding strategy with seat-assignment approach, namely Wave-seat (WS) and Steffen (SF) strategies, has the fastest average boarding time. The concept of the Wave-seat (WS) strategy seems to be able to compete with the speed of the boarding process on the Steffen (SF) strategy and even outperform it. Thisis because the Wave-seat (WS) strategy has a higher frequency distribution of minimum boarding time. In both boarding strategies, some passengers are arranged so that they can put their carry-on luggage simultaneously and sit in their respective seats, starting from window, middle and ending with aisle. In this way, the occurrence of aisle interference can be minimized while seat interference can be eliminated. However, there is a difference way in which by the Wave-seat (WS) strategy, the passengers can store their carry-on luggage and sit on the left and right sides of the aisle at once, while the Steffen (SF) strategy only on one side. Despite achieving the fastest boarding times, the seat-assignment approach requires very strict rules and controls when implementing it compared to other approaches, so that the efforts made by airlines are even greater. These strategies require more time in preparation for boarding to select passengers before they enter the airplane, because they have to be called one by one and not as a group. However, this preparation is not included in the scope of this research.

The boarding strategy with group-assignment and random approach ranks next with slower average boarding time. In this approach, there are three strategies that have very slight differences boarding time, including Wave-group (WG), Reverse-pyramid (RP) and Outside-in (OI). In this case, it can be seen that the Wave-group (WG) strategy can compete with the Reverse-pyramid (RP) and Outside-in (OI) strategies and even outperform them.This is because the Wave-group (WG) strategy has a higher frequency distribution of minimum boarding time. In these three boarding strategies, the passengers get into the airplane randomly according to the call order of their respective group numbers, and go to their seats starting from the window, middle and ending with the aisle. In this way, the possibility occurrence of seat interference can be eliminated, but the aisle interference cannot be avoided. This is because passengers can enter randomly according to the call order of their group numbers without any control over the amount of their carry-on luggage.

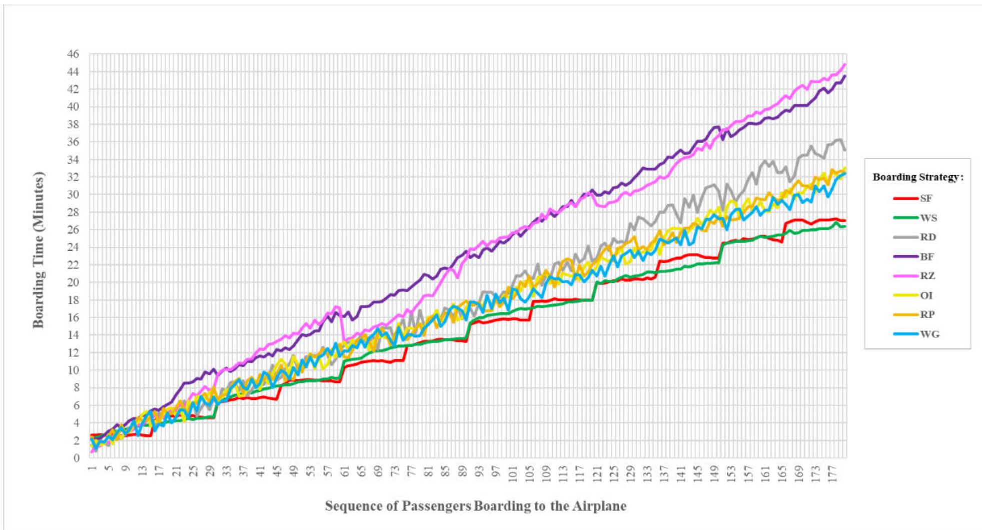


Figure 5. The pattern of boarding time during the normal period with load factor 100% under normal load condition

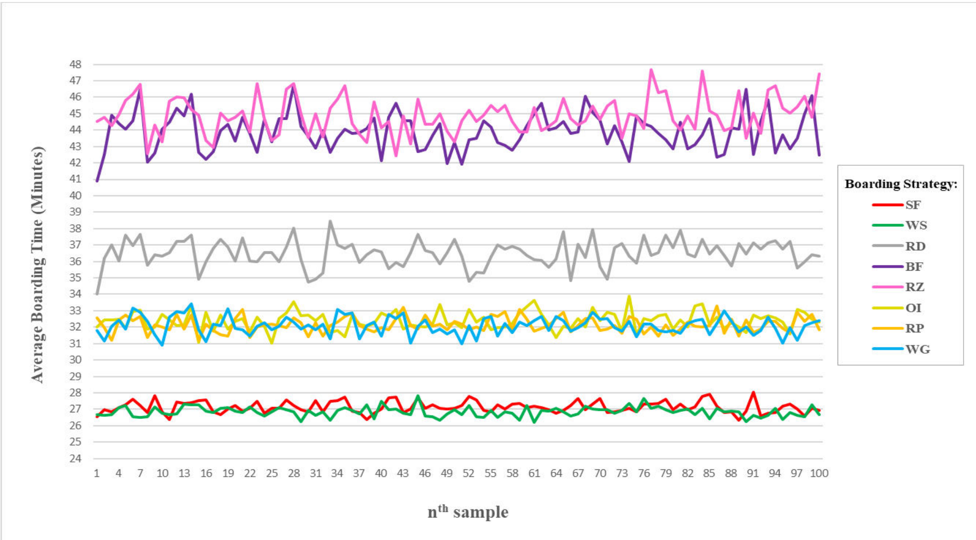
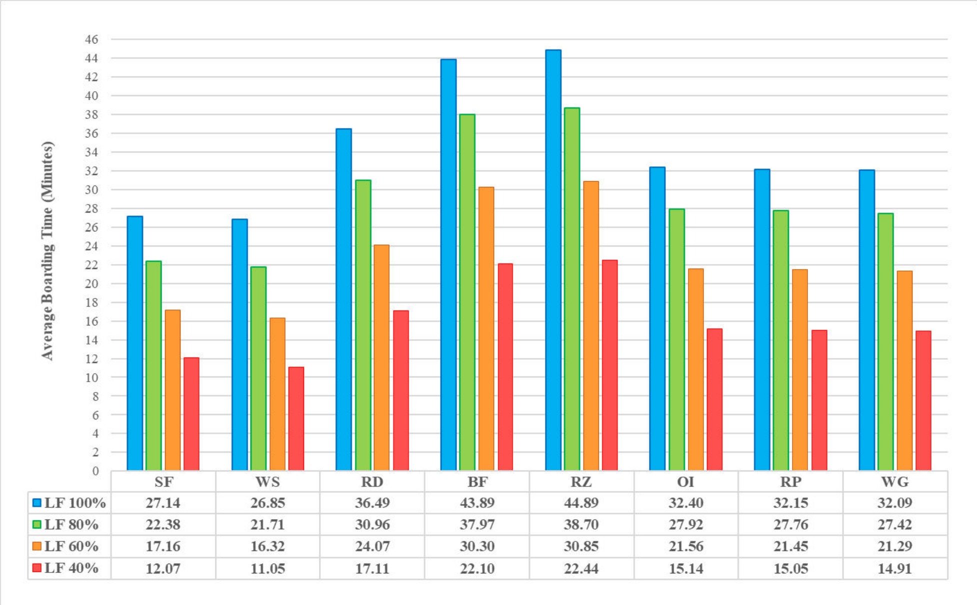


Figure 6. The trend of average boarding time during the normal period with load factor 100%

Random (RA), Back-to-front (BF) and Rotating-zone (RZ) strategies are the strategies with the boarding time that rank in the last. In these three strategies, the occurrence of aisle and seat interferences is unavoidable.This is because the passengers who enter the airplane randomly according to their call order of the group numbers, are not controlled for the amount of carry-on luggage and there are no given arrangements to fill their respective seats, starting from the window, middle and aisle. Although the average boarding times achieved by the random and group-assignment are slower than the seat-assignment approach, their implementation are much easier and faster to understand. In this case, the airlines just need to include the boarding group number on each passenger's boarding pass so that it is easy to understand. Moreover, this method has been implemented, one of which is by Alaska Airlines.



	SF	WS	RD	BF	RZ	OI	RP	WG
LF 100%	27.14	26.85	36.49	43.89	44.89	32.40	32.15	32.09
LF 80%	22.38	21.71	30.96	37.97	38.70	27.92	27.76	27.42
LF 60%	17.16	16.32	24.07	30.30	30.85	21.56	21.45	21.29
LF 40%	12.07	11.05	17.11	22.10	22.44	15.14	15.05	14.91

Figure 7. The average boarding time during the normal period with four different load factors

Based on Figure 7, it can be seen that with a load factor of 80%, 60%, and 40%, the sequence of achieved boarding time from the fastest to the slowest is no different compared to the load factor of 100%. In this research, the average boarding time achieved by the Random (RD) and Back-to-front (BF) strategies seems to be close to the reality on field. In Indonesia, for an airplane with 180 seats configuration, the passenger boarding time with a load factor of 100% will take 35 - 40 minutes if the Random (RD) strategy is used, whereas for the Back-to-front (BF) strategy is 40 - 45 minutes. This shows that the approach applied in this research is quite representative and not just a value on paper. Furthermore, referring to the Figure 7, it can be summarized that for every 20% decrease in passengers load factor during the normal period, the boarding time will also decrease by 6.08 minutes on average.

6.2.2. The Analysis of Passengers Boarding Strategies during the New Normal Period

In the new normal period scenario, the passengers with a maximum number of 120 peoples (load factor 66.7%) will be arranged to enter the airplane according to the chosen boarding strategy by applying 1.0 m, 1.5 m or 2.0 m of social distancing.

a. Passenger Boarding Process by Applying 1.0 Meter of Social Distancing

The average boarding times and frequency distribution achieved by the eight boarding strategies by applying 1.0 meter of social distancing (SD 1.0 m) can be seen in Figure 9, while the boarding time pattern based on the sequence in which passengers enter the airplane can be seen in Figure 8.Here, the boarding strategy with seat-assignment approach, namely Wave-seat (WS) and Steffen (SF) strategies, has the fastest average boarding time.The adaptable concept of the Wave-seat (WS) strategy seems to be able to compete the speed of the boarding process in the Steffen (SF) strategy.Both are designed to provide an additional of 1 seat-row spacing between passengers to balance the applying 1.0 meter of social distancing by the airline. With this concept, several passengers can easily be in their respective seat-row positions without having to wait for other passengers.

In the random and group-assignment approaches, there are two strategies that have very slight difference boarding time, namely Wave-group (WG) and Outside-in (OI). There is an emergent situation where the boarding time of Reverse-pyramid (RP) strategy become slowed down a bit while the Random (RD) strategy gets faster.Although the Reverse-pyramid (RP) strategy has the same concept as the Wave-group (WG) and Outside-in (OI) strategies, especially in eliminating seat interference, but the arrangement of filling seats from the back rowsactually reduces the speed of boarding process. On the other hand, the absence of special instructions and arrangements for filling seats in the Random (RD) strategy, makes the boarding process faster even though the seat interference and aisle interference occur.Meanwhile, Back-to-front (BF) and Rotating-zone (RZ) are the strategies with boarding time taking the last rank.In both strategies, the occurrence of aisle and seat interferences plus the rules for filling seats by the seat-row zone have a significant impact on decreasing the speed of the boarding process.The thing that needs to be considered by the airlines is that the occurrence of seat interference will increase the risks of Covid-19 exposure among the passengers, especiallyin Random (RD), Back-to-front (BR) and Rotating-zone (RZ) strategies. However, these risksare not included in the scope of this research.

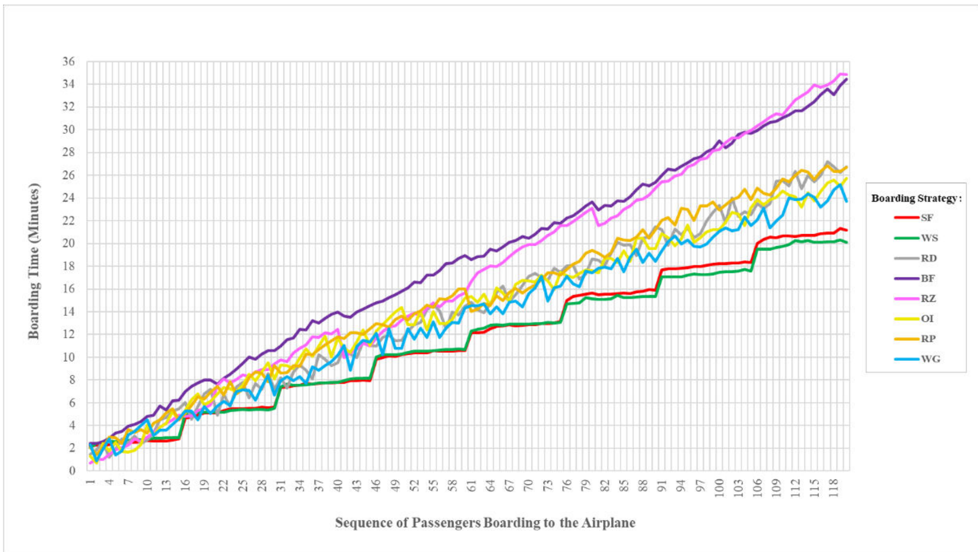


Figure 8. The pattern of boarding time during the new normal period by applying 1.0 meter of social distancing under normal load condition

Figure 9. The trend of average boarding time during the new normal period by applying 1.0 meter of social distancing

b. Passenger Boarding Process by Applying 1.5Meters of Social Distancing

The average boarding times and frequency distribution achieved by the eight boarding strategies by applying 1.5 meters of social distancing (SD 1.5 m) can be seen in Figure 11, while the boarding time pattern based on the sequence in which passengers enter the airplane can be seen in Figure 10.Here the opposite situation occurs in aseat-assignment approach, on which the Wave-seat (WS) strategy achieves the fastest boarding time while the Steffen (SF) strategy becomes the slowest.Although conceptually the two boarding strategies are designed so that passengers can store their luggage simultaneously, the distance between passengers that can be applied by the Steffen (SF) strategy is only 1 seat-row.Therefore, in Steffen (SF) strategy, some passengers have to wait for other passengers to finish the process of storing their luggage into the overhead-bin and only then can move to reach their seat-row position. On the other hand, the Wave-seat (WS) strategy with its flexibility can provide an additional of 2 seat-row spacing as an adaptation and balancing to the implementation 1.5 meters of social distancing.

In the random and group-assignment approaches, there are two leading strategies with very slight boarding time differences, namely Wave-group (WG) and Outside-in (OI).There is unpredict situation where the achieved boarding time of Random (RD) strategy is quite close to the Reverse-pyramid (RP).Meanwhile, Back-to-front (BF) and Rotating-zone (RZ) strategies remain in the last position, along with Steffen (SF) strategy.

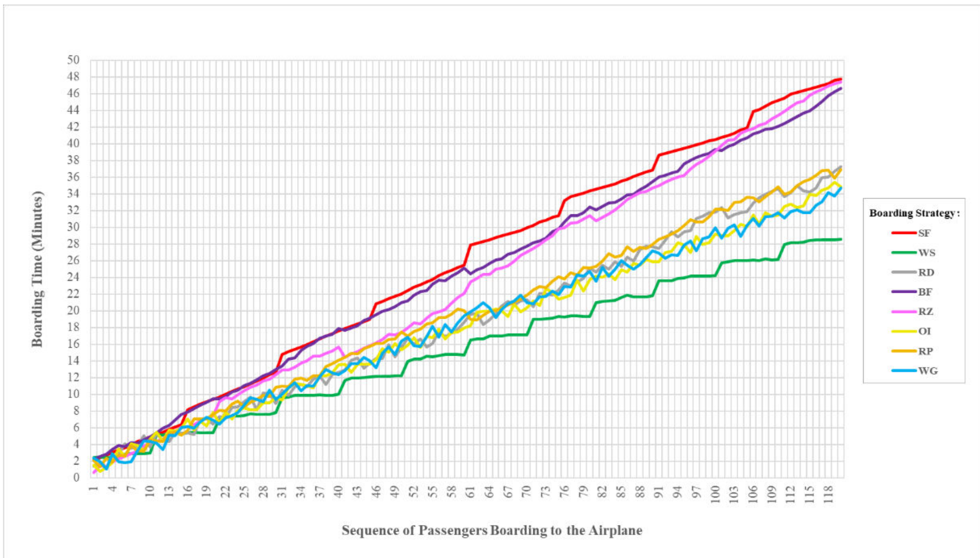


Figure 10. The pattern of boarding time during the new normal period by applying 1.5 meters of social distancing under normal load condition

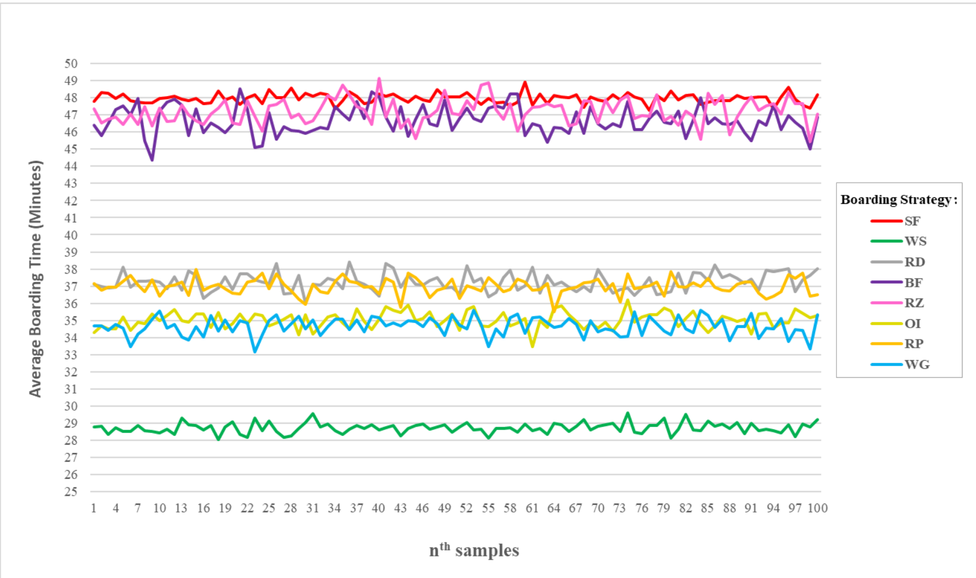


Figure 11. The trend of average boarding time during the new normal period by applying 1.5 meters of social distancing

c. Passenger Boarding Process by Applying 2.0Meters of Social Distancing

The average boarding times and frequency distribution achieved by the eight boarding strategies by applying 2.0 meters of social distancing (SD 2.0 m) can be seen in Figure 13, while the boarding time pattern based on the sequence in which passengers enter the airplane can be seen in Figure 12.Here the same opposite situation also occurs in a seat-assignment approach, on which the Wave-seat (WS) strategy achieves the fastest boarding time while the Steffen (SF) strategy becomes the slowest. Since the spacing between passengers that can be applied by the Steffen (SF) strategy is only 1 seat-row, some passengers have to wait for other passengers to finish the process of storing their luggage into the overhead-bin and only then can move to reach their seat-row position. On the other hand, the Wave-seat (WS) strategy with its flexibility can provide an additional of 3 seat-row spacing as an adaptation and balancing to the implementation 2.0 meters of social distancing.

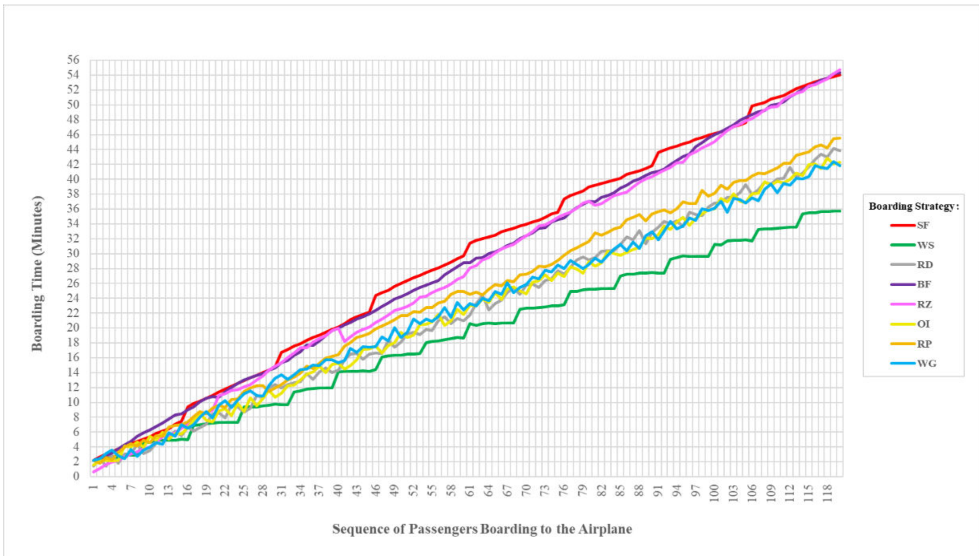


Figure 12. The pattern of boarding time during the new normal period by applying 2.0 meters of social distancing under normal load condition

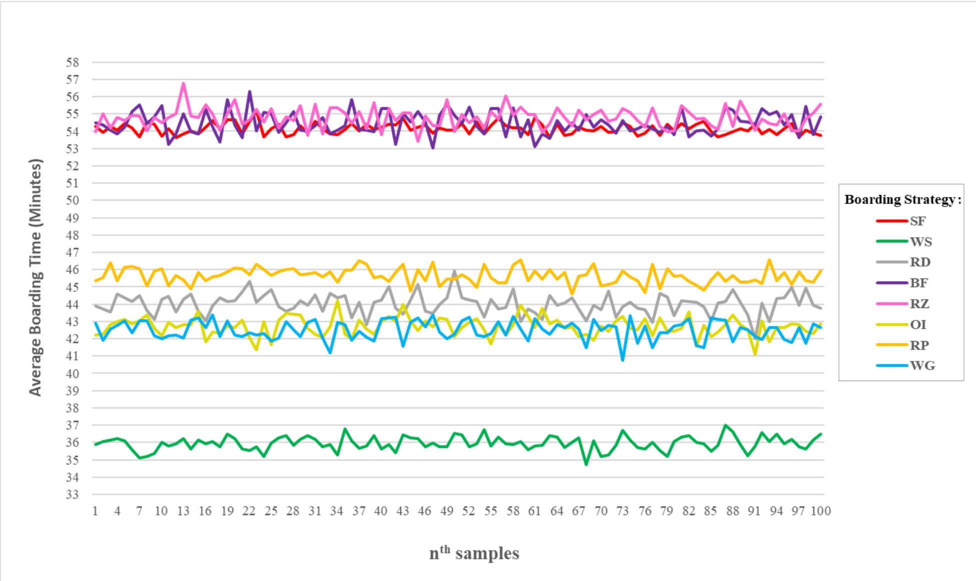
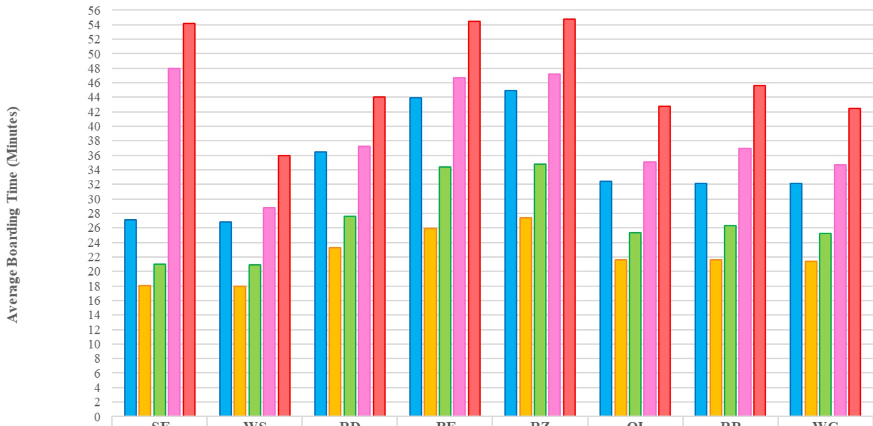


Figure 13. The trend of average boarding time during the new normal period by applying 2.0 meters of social distancing

In the group-assignment and random approaches, there are two strategies that are still leading and have a very slight differences boarding time, namely Wave-group (WG) and Outside-in (OI).There is an emergent situation where the achieved boarding time of Random (RD) strategy is faster than the Reverse-pyramid (RP) strategy. Meanwhile, Back-to-front (BF) and Rotating-zone (RZ) strategies remain in the last position, along with Steffen (SF) strategy.



	SF	WS	RD	BF	RZ	OI	RP	WG
Normal, LF 100%	27.14	26.85	36.49	43.89	44.89	32.40	32.15	32.09
Normal, LF 66.7%	18.02	17.91	23.24	25.93	27.38	21.64	21.58	21.39
New Normal, SD 1.0 m	21.05	20.92	27.64	34.40	34.78	25.36	26.27	25.21
New Normal, SD 1.5 m	47.96	28.73	37.24	46.66	47.21	35.03	36.98	34.66
New Normal, SD 2.0 m	54.15	35.95	44.01	54.47	54.78	42.71	45.64	42.49

Figure 14. The comparation of average boarding time during normal and new normal periods.

Referring to the Figure 14and the previous graphs of frequency distribution achieved by the eight boarding strategies, it can be seen that the Wave-seat (WS) and Wave-group (WG)strategies are very consistent in achieving the fastest boarding time both in normal and new normal periods compared to other strategies. Therefore, the 'Wave' strategy is highly recommended to be implemented on field and become an alternative for the airlines.

In this research, the average boarding time achieved by the Random (RD) and Back-to-front (BF) strategies in new normal period by applying social distancing 1.0 meter seems also to be closeto the reality on field.Based on the authors' experience who made several domestic trips in Indonesia during the new normal period, the average boarding time by applying 1.0 meter of social distancing using Random (RD) strategy is about 25 - 30 minutes while for the Back-to-front (BF) strategy is about 30 - 35 minutes. This shows that the approach applied in this research is quite representative.

6.2.3. The Effect of Social Distancing to the Effectiveness Boarding Strategy

The applying social distancing during the new normal period of post Covid-19 pandemic is intended as a risk mitigation so that airplane passengers can avoid the possibility of exposure to the Covid-19 virus. Here, if we compare the average boarding time with the scenario during the normal period with a load factor of 100% and the new normal period with a load factor of 66.7% as shown in Figure 15, it can be seen that the average boarding time by applying 1.0 meter, 1.5 meters and 2.0 meters of social distancing are in the range of 78.21%, 116,06% and 138.29%.This comparison is made by considering the maximum number of seats that can be occupied by the airplane passengers during normal and new normal periods.

Referring to **IATA (2020c)**which states "On average airlines break even at a load factor of 77%", it can be assumed that the average boarding time with a load factor level of 66.7%, ideally applying the distance between individuals in a range that does not exceed the calculation result of 77% of boarding time during the normal period with load factor 100%. The assumption uses this approach because the achieved boarding time in the normal period with a load factor of 77% can produce different data if the passengers'seat positionshave different setting scenario, such as spreadingover all seat-row or filling the front seat-row only.Therefore, the implementation of social distancing during the boarding process that is recommended for airlines so that their business performance does not experience a greater loss impact, is located at a distance of 1.0 meter where the average boarding time is closest to the boarding threshold of 77%.

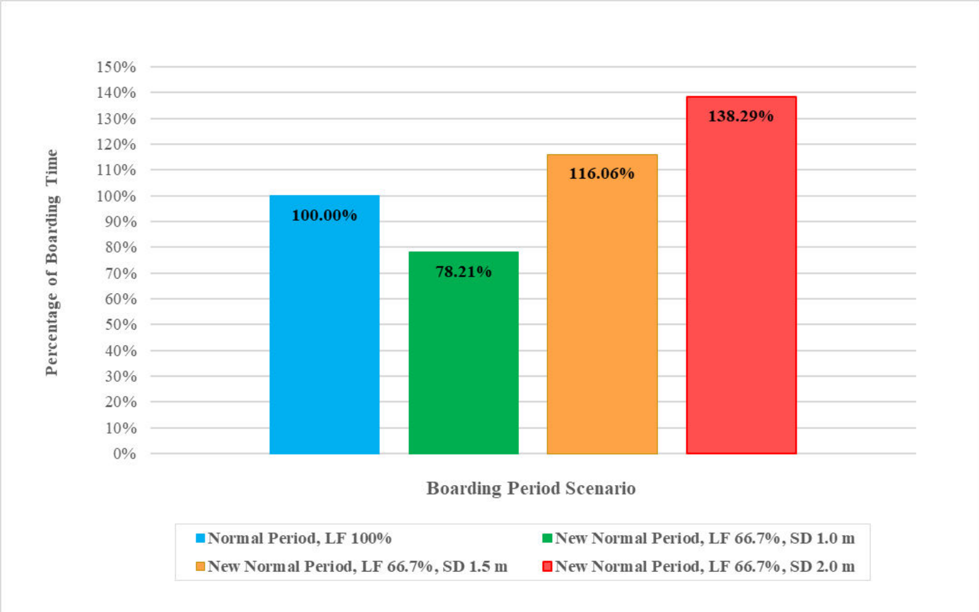


Figure 15. The gap percentage of average boarding time during the normal and new normal period, with consideration the maximum number of seats that can be occupied by the passengers

In line with the case, this research also performs the analysis of the Chi Square test of independence to determine how the social distancing affects the effectiveness of the boarding strategy. The observation data were taken from the simulation output with the scenario of the new normal period by applying 1 meter of social distancing under normal load conditions. The threshold set is the calculation result of 77% of boarding time during the normal period with load factor 100% as shown in Table 4, while the mapping of simulation output data with values that are distributed above and below the specified threshold (contingency table) can be seen in Table 5.

Table 4. The reference of boarding time threshold for Chi Square test of independence

Boarding strategy	**Boarding time (minutes)**	
	Output simulation during the normal period with load factor 100%	**Threshold of ideal boarding time during new normal period (b = 77% * a)**
	(a)	(b)
Steffen (SF)	27.14	20.89
Wave-seat (WS)	26.85	20.67
Random (RA)	36.49	28.10
Back-to-front (BF)	43.89	33.79
Rotating-zone (RZ)	44.89	34.56
Outside-in (OI)	32.40	24.94
Reverse-pyramid (RP)	32.15	24.76
Wave-group (WG)	32.09	24.71

Table 5. Frequency distribution of average boarding time during the new normal period with values above and below the threshold

Implementation of social distancing	Boarding strategy								Total
	SF	WS2	RD	BF	RZ	OI	RP1	WG	
Affects the effectiveness boarding strategy	54	63	21	52	33	46	95	57	421
Does not affects the effectiveness boarding strategy	46	37	79	48	67	54	5	43	379
Total	100	100	100	100	100	100	100	100	800

Here by inserting the contingency table to the Chi Square test of independence statistical formula or using IBM SPSS 26 software, it is obtained that $\chi^2_{compute}$ = 134.53. Furthermore, by using Chi Square table, the critical value is obtained with the level of significant (α) = 0.05 and degree of freedom (df) = 7, thus $\chi^2_{\text{table}} = \chi^2_{0.05;7}$ = 14.0671.

Since the observed value of Chi Square 134.53 is greater than the critical value of Chi Square, 14.0671, then the decision is to reject the null hypothesis (H_0) and accept the alternative hypothesis (H_1). With a significant level of 5%, it can also be interpreted that the implementation of social distancing is highly correlated to the effectiveness boarding strategy.

7.Recommendations

- For further research, especially to find the effective boarding strategy, the model and technique in this research can be implemented in a scenario using front and rear doors of the airplane, in which only few literatures have considered this type of boarding.
- Several scenarios can also be added such as arranging the passenger's seat allocation based on the amount of their carry-on luggage, combining with group boarding, and so on.
- The probability risks of Covid-19 exposure between passengers can be included on the next airplane boarding research.

8.Conclusions

This research has succeeded in designing simulation model of airplane passenger boarding strategies with scenario both in normal and new normal periods using agent-based simulation in NetLogo 6.1.1. The simulation results show that the Wave strategy which is implemented through the seat-assignment (Wave-seat) and group-assignment (Wave-group) has successfully demonstrated its effectiveness and become an alternative to be applied by the airlines, for both in normal and new normal periods.

Moreover, based on simulation data on this research, for every 20% decrease in passengers load factor during the normal period, the boarding time will also decrease by 6.08 minutes on average.By comparing the average boarding time with scenarios during the normal period (load factor 100%) and the new normal period (load factor 66.7%), then the average boarding time by applying 1.0 meter, 1.5 meters and 2.0 meters of social distancing is in the range of 78.21%, 116.06% and 138.29%. This research has found and recommend to apply 1 meter of social distancing where the average boarding time is closest to the boarding threshold of 77%.Furthermore, by using Chi Square test of independence analysis, it can be seen that the implementation of social distancing is highly correlated to the effectiveness boarding strategy since the observed value of Chi Square is greater than the critical value of Chi Square.

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