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Study of Passenger Evacuation from the Airbus A330-300 Aircraft †

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Abstract: This study is a simulation of the evacuation of the passengers from the Airbus A330-300 aircraft and the objective is the efficient evaluation of passenger evacuation and to find the most efficient evacuation format. The Pathfinder simulation program is used for this study. The study is divide into two parts. The first scenario of the evacuation from the aircraft is using all exit doors simulated in 4 formats of evacuation tests as follows: Format (1) evacuate freely. Format (2) evacuate divided by area. Format (3) evacuate which passengers are determined to evacuate to the nearest exit door. Format (4) evacuate which the number of passengers evacuating via each exit door is equal. The result of the simulations indicated that the evacuation times were 50.9, 79.4, 50.6, and 58.6 s, respectively. The most efficient evacuation was format 3 and insignificantly different from format 1. The second scenario is the evacuation which 1 left-side exit door is unavailable and is simulated in format 1–4 as same as the first scenario. The shortest time of the evacuation with exit door 1L, 2L, 3L, and 4L unavailable were 51.3, 58.5, 62.6 and 59.3 s, respectively. The most efficient format for the evacuation with exit door 1L unavailable was format 1 and 3 while format 1 was the best for the evacuation with any left-side exit door unavailable. Accumulation and density of passengers in the cabin were analyzed and evacuation formats were adjusted by seat row for finding the shortest evacuation period. The adjusted format was simulated again and the evacuation times with door 1L or door 4L unavailable can be slightly decreased and the times were 49.3 and 59.0 s. The simulation of these two scenarios found that the best way to use for the aircraft evacuation is to evacuate freely.

Keywords: aircraft evacuation; A330; aircraft safety; Pathfinder; evacuation simulation

1. Introduction

Emergencies can occur at any time. Emergency preparedness is important and necessary for aviation industry. Emergency evacuation from an aircraft is necessary for the safety of passengers. The more rapidly an evacuation is initiated and is efficiently conducted, the more likely the number of injuries and fatalities to occupants will be reduced.

According to International Civil Aviation Organization (ICAO) requirement, the Emergency Evacuation Provisions in Circular 55-AN150/2 required that all the passengers for which the airplane is certificated can evacuate within 90 s. Currently, the certification only conducted by aircraft manufacturers.

Aircraft evacuation drill must be conducted regularly. Normally, only the crew will annually practiced following the air operator's procedure which is required by the Civil Aviation Authority of

Thailand (CAAT) to ensure that the crew can correctly practice in an emergency situation. Majority of airlines do not practice with whole passengers in the aircraft seats because of a lot of constraints such as a security issue of the airport, the large and proper area in airside, risk of inexperienced occupants who might be injured, and spend a lot of money.

Hence, the aircraft evacuation simulation by the software can help efficiently evaluating the passenger evacuation in an abnormal situation. The software can reduce the time period and expenses. The Pathfinder software will be used for studying and analyzing the evacuation behavior of passenger in this study.

2. Basic Backgrounds

2.1. Aircraft Accident Statistic

The report from National Transportation Safety Board—NTSB, USA (NTSB/SR-01/01), from 1983 through 2000, the Safety Board investigated 26 accidents involving fire, serious injury, and either substantial aircraft damage or complete destruction. There were 2739 occupants involved in these serious accidents.

1524 (55.6 %) survived

716 (26.1 %) died from impact

340 (12.4 %) died from unknown causes

131 (4.8 %) died from fire/smoke

28 (1.0 %) died from other causes

Any cause of deceased passenger cannot be reduced such as impact from aircraft accident but in case of fire can reduce a death rate of passengers if theirs correctly and timely evacuate form the aircraft before the smoke thoroughly generates in the cabin.

The Aircraft Accident Statistics and Knowledge (AASK) database [1] is a store of survivor accounts from aviation accidents. AASK database was developed by Fire Safety Engineering Group, University of Greenwich. Its main purpose is to store observational and anecdotal data from interviews of the occupants involved in aircraft accidents.

The AASK database is a unique resource containing data from over 2000 passenger and crew accounts from 105 survivable accidents. The data in AASK is extracted from accident investigation transcripts supplied by the Air Accident Investigation Branch in the UK, the National Transportation Safety Board in the US and the Australian ATSB.

AASK database analyzed the evacuation of passenger from the aircraft follow.

2.1.1. Nearest Exit Usage

The results from the analysis using AASK V4.0 confirm this observation with 85% of passengers who report their exit usage making use of the nearest available exit.

2.1.2. Distance and Direction Traveled by Survivors during Egress

The direction of passengers when evacuating show that 60% travelled forward, 34% travelled towards the rear, while the remainder were situated within an exit row. These results may suggest that passengers have a propensity for travelling forward.

However, of those passengers choosing to travel forward, 64% have selected their nearest exit, while for those choosing to travel towards the rear, 67% have selected their nearest exit. This suggests that the overriding inclination of the passengers is to exit via their nearest exit.

2.2. Factor Involved with Evacuation

2.2.1. Evacuee

Gender determines whether males and females behave differently during the evacuation. For example, women have a shorter pre-evacuation time than men and they also behave differently in finding the origin of the fire, helping others to evacuate, evacuating from the building and calling the fire brigade.

Age of people influences individual physical, psychological and social behavior, which has an impact on pedestrian evacuations. The elderly have longer reaction times or are slower to travel than normal adults during an evacuation.

Body Size Body dimensions influence a passenger's occupied space and population density in an environment. The size of a human torso is defined as body width, which is measured from shoulder to shoulder, and body depth, which is measured, by chest depth [2].

Group behavior examines whether people who accompany others behave differently to individuals. For example, occupants' response times, travel speeds, and navigation behaviors change when they observe the behavior of group members, and delays are often caused by people gathering family and friends before starting to evacuate.

2.2.2. Aircraft Configuration

Type or model of the aircraft influences the evacuation time because the exit doors are different which there are Floor level exit (door type A, type I), Over wing exit (door type III), etc. The door dimensions of each type are different too. Although, the aircraft is the same type in many airlines, the cabin layouts are different such as the type of seat, the number of seat, seat dimensions, aisle size and other facilities in aircraft that effect the evacuation time.

2.2.3. Evacuation Environment

Environment for evacuating in case aircraft catching fire from outside may cause-effect for the operation of an emergency door. The emergency door which locates near the area of fire may not work properly from safety concern. Passenger will be in danger from opening an emergency door for evaluation. In the event of aircraft catching fire from inside, it also can cause trouble such as smoke and toxic gas for the evacuation.

If the aircraft lands on water or sloping area some of the emergency doors may not be in good condition because the emergency slide might not touch the ground. It might cause danger to evacuate passenger during this time. Time for passenger evacuation might be changed if aircraft doesn't land at a proper level.

3. Simulation Software and Methodology

3.1. Software Selection and Validation

Simulation software will be selected by reviewing the theses that collected 8 software, namely airEXODUS [3], Pathfinder [4], Simio, Kring Model, ESS-AIR, GUI, Math Lab, DES and ARENA® 14. The criteria have been set for choosing the most suitable software as detail following: Ability of software, Distinctiveness with an aircraft, Availability of software information, Use frequently in theses, Software fee, Knowledge of software. After consideration found airEXODUS and Pathfinder software were interested and the strong and constraint point of both software was compared and found that the Pathfinder is the best suitable for this study. Therefore Pathfinder software has been used to simulate 2 cases for testing the accuracy of software as follow.

3.3.1. Case Study 1

Reference [5] studied the evacuation from Boeing 737 involving 2 exits and 60 Passengers, this case compare between evacuation trial by Cranfield University and simulation by airEXODUS software which the average of evacuation times of 55 passengers were 42.7 and 41.2 s. Pathfinder software was tested to compare with both of method. Test result by Pathfinder software found that the evacuation time was 43.2 s which a little different from the trial by Canfield and airEXODUS software. The evacuation time are shown in Table 1.

Table 1. Evacuation time comparison of trial by Cranfield, airEXODUS & Pathfinder in case study 1.

Time (s)	Cranfield (Trial)	AirEXODUS	Pathfinder
Minimum	37.1	38.4	39.5
Mean	42.7	41.2	43.2
Maximum	43.2	44.1	45.1

3.1.2. Case Study 2

The evacuation from Boeing 767 involving 4 exits and 285 Passengers, this case compare between evacuation trial and simulation by airEXODUS software which the evacuation times of trial was 72.6 s and the average of evacuation times by airEXODUS software was 73.1 s. Pathfinder software was tested to compare with both of method. Test result by Pathfinder software found that the average evacuation time was 74.9 s which different from the trial and airEXODUS software approximately 2 s. The evacuation time are shown in Table 2.

Table 2. Evacuation time comparison of trial, airEXODUS and Pathfinder in case study 2.

Time (s)	Trial	AirEXODUS	Pathfinder
Minimum	-	68.0	70.5
Mean	72.6	73.1	74.9
Maximum	-	80.0	78.1

3.2. Pathfinder Simulation Setup

Hence, the Pathfinder software can use for simulation of aircraft evacuation.

3.2.1. Create an Aircraft Diagram in Pathfinder

Study cabin configuration of Airbus A330-300 [6,7] e.g., the width and length of the aisle, exit door positions and dimensions, seat size and the facility in the cabin area for using to create aircraft diagram in Pathfinder software.

3.2.2. Determine the Parameter

Determine parameter in Pathfinder software, consist of evacuee gender, evacuee height, evacuee shoulder width, movement speed, door flow rate and door operating time are shown in Table 3.

Table 3. Parameter which determined in Pathfinder software.

Parameter	Male	Female
Gender (%)	44.3	55.7
Height (cm) [8]	169.1	157
Shoulder width (cm) [6]	44.1	40.5
Movement speed (m/s) [9]	2.44	
Door operating time (s) [9]	2.25	
Door flow rate type A (person/s) [9]	2.105	

3.2.3. Determine Gender on the Seat

Normally, the gender distributions of passengers are different from each flight which will affect evacuation time. The gender of passenger has been collected from an anonymous airline in 2018. Then, SPSS will be used to random gender for seats.

3.2.4. Evacuation Format

The evacuation from the aircraft is using all exit doors simulated in 4 formats of evacuation tests as follows;

Format 1 Evacuate freely.

Format 2 Evacuate divided by area.

Format 3 Evacuate which passengers are determined to evacuate to the nearest exit door.

Format 4 Evacuate which the number of passengers evacuating via each exit door is equal.

The evacuation which 1 left-side exit door is unavailable which determined 1L, 2L 3L or 4L and is simulated in format 1–4 as same as above. The 4 evacuation formats are shown in Figure 1.

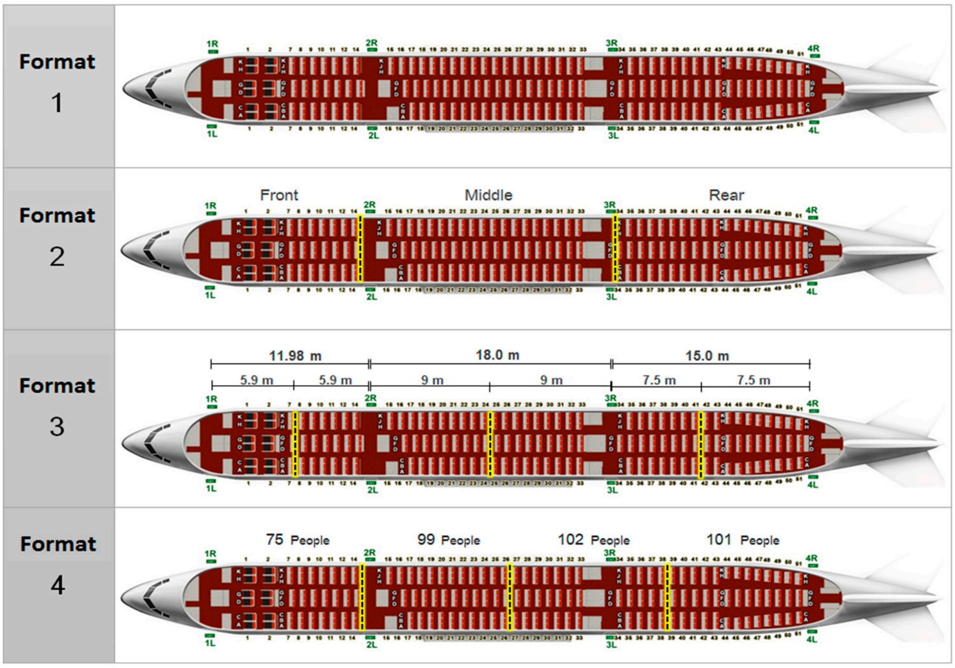

Figure 1. Seat row assignment in each format.

4. Results

4.1. The evacuation Is Using All Exit Doors

Evacuation in format 1: Evacuate freely from the aircraft which contained 377 passengers. The evacuation time of format 1 was 50.9 s.

Evacuation in format 2: Evacuate from the aircraft divided by area that there are 3 areas, including the front, middle and rear of the aircraft. The passengers who seated in the front area evacuated to the exit door located at the front of aircraft that there is door 1 (1R and 1L). The passengers who seated in the middle area evacuated to the exit doors located at the middle area that there are door 2 and door 3 (2R, 2L, 3R and 3L), the passengers who seated in the rear area evacuated to the exit doors located at the rear of the aircraft that there is door 4 (4R and 4L). The evacuation time of format 2 was 79.4 s.

Evacuation in format 3: Evacuate from the aircraft which passengers were determined to evacuate to the nearest exit door. The longitudinal distance between exit doors was separated at the middle and any seat rows near any exit doors were determined to evacuate to that way. The evacuation time of format 3 was 50.6 s.

Evacuation in format 4: Evacuate from the aircraft which the number of passengers evacuating via each exit door is equal. The passenger who seated on the business seats and the economy seats at the front evacuated to the exit door 1 which contained 75 passengers and the other seats were separated approximately 100 passengers evacuating to each exit door. The evacuation time of format 4 was 58.6 s. The evacuation times for 4 formats are shown in Figure 2 and seat row assignment for 4 formats are shown in Table 4.

The analysis indicated that an accumulation and congestion of passenger have occurred at the aisle in the middle of the aircraft and that area has a lot of passengers and the distance at the middle of aircraft is farthest from exit doors. The analysis concluded that the distance and number of passengers affects evacuation time.

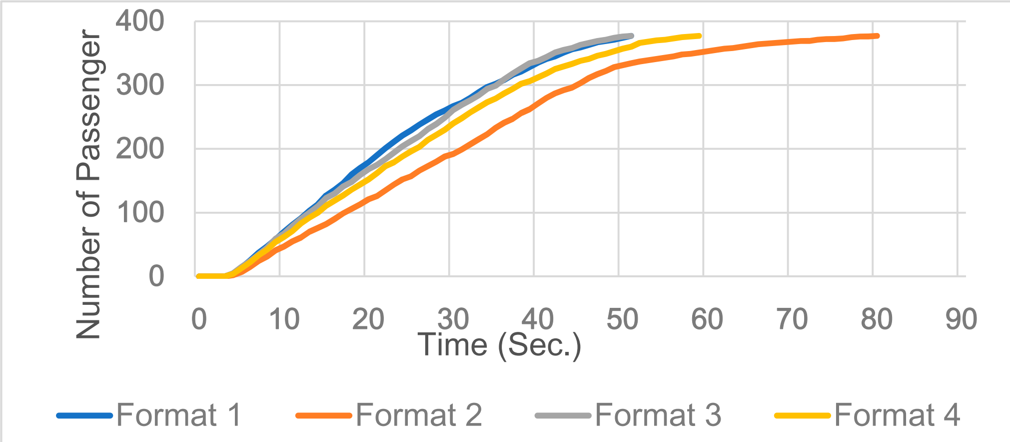

Figure 2. The evacuation times of 4 formats.

Table 4. Seat row assignment in each format.

Format	Seat Row Assignment			
	1R, 1L	2R, 2L	3R, 3L	4R, 4L
Format 1	<----------- Not determined ----------->			
Format 2	1–14	<---- 5–33 ---->		42–51
Format 3	1–7	8–24	25–41	42–51
Format 4	1–14	15–26	27–38	39–51

4.2. The Evacuation which 1 Left-Side Exit Door Is Unavailable

This study simulated in case that 1 exit door is unavailable, since the aircraft shape is symmetry in each opposite side (Left—Right) and the exit door located in the same position then the left-side of exit door is chosen that there are 1L, 2L, 3L or 4L unavailable and simulated in format 1–4 as same as the case that all exit door is available.

The most efficient format for the evacuation with exit door 1L unavailable was format 1 and 3 while format 1 was the best for the evacuation with any left-side exit door unavailable. The shortest time of the evacuation with exit door 1L, 2L, 3L, and 4L unavailable were 51.3, 58.5, 62.6, and 59.3 s, respectively. The evacuation times in each case are shown in Table 5.

Table 5. Evacuation time in case of 1 exit door is unavailable.

Format	Evacuation Time in Case of 1 Exit Door Is Unavailable (s)			
	1L	2L	3L	4L
Format 1	51.3	58.5	62.6	59.3
Format 2	82.2	81.0	80.0	155.4
Format 3	51.3	98.5	95.1	85.2
Format 4	82.0	117.5	76.1	112.4

4.3. Format Adjustment

Accumulation and congestion of passengers in the cabin were analyzed and evacuation formats were adjusted by seat row for finding the shortest evacuation period. The colors represent density level of passenger which was used for analyzing strong point and week point of evacuation, the colors and density level are shown in Figure 3.

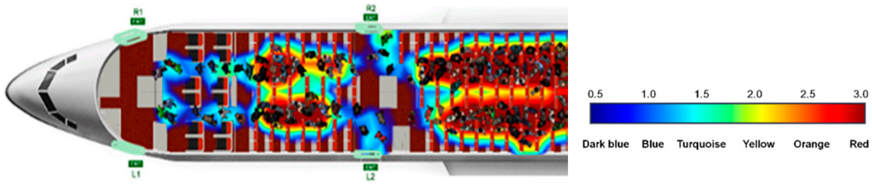

Figure 3. The density level of passenger displayed. The colors represent density level of passenger (Occs/m^2).

The format adjustment is considered as follow;

1. Analyze all formats about strong point and weak point.
2. Focus on the exit door selection of the last evacuee and adjust a seat row which the last evacuee seated to evacuate in another direction.
3. Consider the passenger density in each second and each area and compare the congestion between separated areas. The area which has more congestion than another, a seat row that area will be changed to another direction are shown in Figure 4.
4. Adjust continually until getting the shortest evacuation time.

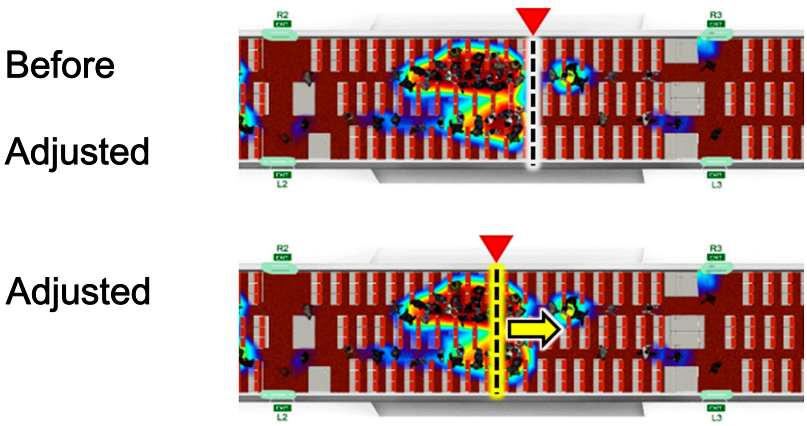

Figure 4. How to adjust seat row by analyzing density of the passengers.

The result of the best adjusted formats compares with the best previous format are shown in Table 6.

Table 6. Comparison of best adjusted formats and the best previous format.

Door	Format	Evacuation Times (s)	Seat Row Assignment			
			Door 1	Door 2	Door 3	Door 4
All door available	Format 3	50.6	1–7	8–24	25–41	42–51
	The best adjusted format	52.6	1–7	8–25	26–41	42–51
1L door unavailable	Format 1 and Format 3	51.3	<-------- Not determined -------->			
			1–7	8–24	25–41	42–51
	The best adjusted format	49.3	1–9	10–24	25–41	42–51
2L door unavailable	Format 1	58.5	<-------- Not determined -------->			
	The best adjusted format	66.0	1–11	12–21	22–41	42–51
3L door unavailable	Format 1	62.6	<-------- Not determined -------->			
	The best adjusted format	68.2	1–9	10–28	29–39	40–51
4L door unavailable	Format 1	59.3	<-------- Not determined -------->			
	The best adjusted format	59.0	1–9	10–24	25–44	45–51

4.4. The Evacuation Which 2 Exit Doors Are Unavailable

Aircraft accident statistic found that there are many cases of exit doors involved evacuation. The aircraft evacuations have additionally been simulated reference the statistic which the opportunity of 2 exit doors are unavailable that there are Door 3R, 3L Door 4R, 4L and Door 3L, 4L. The aircraft evacuations are simulated in Format1 (freely) which is optimal. The results are shown in Table 7.

Table 7. Evacuation time in case of 2 exit doors are unavailable.

Unavailable Doors	Evacuation Times (s)
3R & 3L	86.5
4R & 4L	88.4
3L & 4L	78.7

5. Conclusions

The evacuation from the aircraft is using all exit doors simulated in 4 formats. The result of the simulations indicated that the evacuation times were 50.9, 79.4, 50.6, and 58.6 s, respectively.

The analysis of the information from the Pathfinder software found that accumulation and congestion of the passenger have occurred at the aisle in the middle of the aircraft and that the area has a lot of passengers and the distance at the middle of aircraft is farthest from exit doors. The analysis concluded that the distance and number of passengers affect evacuation time.

Simulation in case that 1 left-side of exit door is unavailable that there are 1L, 2L, 3L and 4L unavailable door and simulated in format 1–4 is described as follows;

The most efficient format for the evacuation with exit door 1L unavailable was format 1 and 3, the evacuation times was 51.3 s. The second and third were format 4 and format 2, the evacuation times were 82.0 and 82.2 s, respectively.

The most efficient format for the evacuation with exit door 2L unavailable was format 1, next were format 2, format 3 and format 4, the evacuation times were 58.5, 81.0, 98.5 and 117.5 s, respectively.

The most efficient format for the evacuation with exit door 3L unavailable was format 1, next were format 4, format 2 and format 3, the evacuation times were 62.6, 76.1, 80.0 and 95.1 s, respectively.

The most efficient format for the evacuation with exit door 4L unavailable was format 1, next were format 3, format 4 and format 2, the evacuation times were 59.3, 85.2, 112.4 and 155.4 s, respectively.

The seats configurations or the layout inside the cabin are specific and cannot be changed. The seat row adjustment might decrease the evacuation time. The researcher has analyzed the accumulation and density of passengers in the cabin while evacuating in each second and try to adjust passengers to evacuate to exit doors which determined. Evacuation times can be decreased in 2 cases, the first case was door 1L unavailable, the evacuation time was 49.3 s, decreased 2 s. The second case was door 4L unavailable, the evacuation time was 59.0 s, decreased 0.3 s.

The simulation of these scenarios including all exit door available, 1 left-side door unavailable and adjusted format found that the majority of the most efficient format was format 1, the evacuation time of the other formats are slightly different. Then, it can be concluded that the best way to use for the aircraft evacuation is to evacuate freely.

According to aircraft accident statistic, the researcher additional simulated in case of 2 exit doors are unavailable that there are Door 3R, 3L Door 4R, 4L and Door 3L, 4L. The evacuation times were 86.5, 88.4, and 78.7 s, respectively.

Comparison of aircraft evacuation by using all exit doors and the exit door is unavailable found that 1 exit door is unavailable, effecting to increase of evacuation time. The 2 exit doors are unavailable, effecting to increase of evacuation times more than 1 exit door is unavailable.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "conceptualization and methodology, P.C. and C.T.; software and validation, P.C.; formal analysis, and investigation; P.C. and C.T.; resources, data curation, and writing—original draft preparation, P.C.; writing—review and supervision, C.T. All authors have read and agreed to the published version of the manuscript.

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