Modeling Of Passenger Egress From Aircraft Fire For Safety.

Odigie D.O. Yamen Systems Services, New York, NY 10458.

ABSTRACT

This paper presents the simulation of occupants egress from aircraft using stochastic modeling. A typical aircraft-seating configuration is used with determined exits locations. The points of the aircraft of high fire hazards are used as possible ignition points. Fire is identified as a greater hazard than smoke due to the availability of oxygen mask. Fire spread is then modeled in a network representation. The aircraft is considered to be made up of nodes and edges (aisle, stairs). Nodes are sections of the aircraft without demarcation or volumes not exceeding the reasonable space occupied by a passenger seat. Large volumes are subdivided into smaller nodes to ensure the uniformity assumption. To each edge is a corresponding random variable representing the time of moving from one node to another. The investigation includes comparison of egress with/without occupant interrelationship or dependency. Dependency occurs when an occupant assists or is assisted by any other. A set of hazard function is used to make it possible to follow the time evolution of the fire scene step by step and to modify the probabilities that drive the model at any step in accordance with the interactions that eventuate. Occupants behavioral and response time differences are classified into categories to reduce complexities. Histograms and cumulative distribution of time to evacuate are given. The probability of evacuating the aircraft for any given time is obtained.

Similar modeling technique can be used to evaluate the influence of the number and location of exits, adequacy of hazard management, and evacuation of educational programs.

Keywords: Stochastic, probability, aircraft, egress, evacuation, hazard, passenger, safety, Modeling, Migration, Hazard, Safety, Fire

1. INTRODUCTION

The simulation calculates the evacuation time for one type of aircraft. The same can be performed for other types and the comparative analysis will determine the advantages of the spatial distribution of the passengers, the location of the exits and many other factors that enhances the probability of survival.

The input can consists of the outside and aircraft temperatures, and the temperature of the source of fire. Pressure generated by any mechanical device (ventilation and exhaust systems) are disregarded as they are assumed to be non operational. Otherwise the simulation would consider the partial pressures and the mass flow rate into the exhaust system.

Simulation strategies:

- In order to investigate the effect of a variable, such as location of exits, all others are held constant.
- Among others, fire and smoke models use the following techniques: Field Model, CFD Model, and Network Model. In this paper the Hazard function is used to effect the node transitions in a network. The fire hazard to an occupant increases as time elapses, therefore sets of an increasing order Hazard function that defines the probability of survival or otherwise of the occupant's egress is used. This is effected by sorting the state space of the process in ascending order depicting the increasing order of hazard severity.
- In a compartmentalized structure the doors and windows are the links to the adjacent nodes. But in this case, a node is taken as a virtual enclosure without physical boundaries. Hence fire or smoke can spread through any of the virtual sides. This removes the orifice effect; the orifice flow constant is then unity.

Assumptions

- Survival is reached when a passenger passes through an exit before the untenable conditions is reached at the current node or exit concerned; otherwise a casualty results.
- Classification of passengers into groups or vulnerability index depends on the agility and well being. Four levels are taken as sufficient to cover all types of passengers. Grouping and classifying can be a main investigation by itself as it depends on age, health, prior knowledge of exits, and survival instincts. These factors are by themselves not exhaustive.
- A typical aircraft configuration of Boeing 737-600 model is assumed. For simplicity, the only source of fire is one of the engines; and 10 passengers are taken for simulation. An elaborate simulation would include all passenger seating positions and more possible sources of fire.
- Heat transfers from the incoming gas and or fire to the walls and also to the assumed uniform space in the compartment (node) occur within one unit time step. A time step is the smallest unit after discretization of the index parameter defined below.
- For lack of data, the effect of fire and or smoke is represented by an increasing or decreasing order of a chosen hazard function depending on if the direction of migration is towards or away from the source of fire.

A stochastic process X(t) is defined by the following quantities [3]:

(a) State space
(b) Index parameter (time)
(c) Statistical dependencies between the random variables (r.vs) X(t) for different values of the index parameter t.

2. Passengers Classification

The ability of a passenger to egress depends on many factors, some of which are interdependent. These factors include age, health, agility, consciousness, prior knowledge, concerns, sex, etc. These determine the vulnerability of a passenger. For ease, they can be classified into groups indexed ranging from the least to the most vulnerable, 1 to 4. Hence passengers can be classified into groups depending on their mobility and response to cues. See the Table 1 below.

Table 1 Group Classification of Passengers (5):

Group	**Speed (ft/s)**	**Speed (m/s)**	**Description**
1	5.25	1.6	Very Mobile: e.g. Physically and Psychologically fit to Evacuate
2	3.3	1.0	Mobile: As above but with reduced mobility.
3	2.8	0.85	Reduced Mobility: Children and Aged.
4	1.6	0.5	Assisted Mobility: Mobile only if assisted e.g. Wheelchairs

The simulation stochastically draws from the state space of the stochastic process. The state space is the set of possible values (or states) that a process may take. In the particular case of the class a passenger belongs, it is assumed that there is no statistical dependency between the groups as defined. Interdependency is discussed later. Since a draw from the available group above may take only finite or countable values it is a discrete-state process. Occupancy can be grouped into the above classes. For instance, if there are 10 occupants, classifying entails identifying and allocating them stochastically to groups as shown in the above table. Historical data would be most appropriate in determining the distribution that would fit the composition of passengers; hence obtaining the percentages belonging to each group, that may depend on the seasons and major human activities. Otherwise it is usual to assume a probability distribution that is chosen based on expert or reasonable experience. For lack of data the latter is used in this simulation. There is no sufficient data to reflect a reasonable distribution for the type of passengers. It is assumed here that more of the young and middle aged use aircraft. Hence the uniform distribution would not be adequate. The log normal is a good choice.

The effluent in pyrolysis (Transformation of a substance produced by the action of heat) depends on the type of fuel load. Since fire is dynamic, devouring different types of fuel as it progresses, it stands to be a variable except where there is only a type of load in the path and fire history. In the event of varying fuel type consumption the constitution of gases and type of fire progressively changes. Common classification of fire type are smoldering, flaming, and flashover.

Untenable condition is reached at an exit when the fire becomes so large that passing through is not possible. Or when an occupant that is evacuating is so disoriented as not to be able to pass through an exit. This defines the end of the time available for escape. The heat release rate (HRR) that would incapacitate varies from 350 - 400 kilowatts (7). The time to reach the incapacitating heat release rate will be the time during which there is survival. As the occupant egresses the simulation determines the accumulation of heat radiation and convection while comparing with the incapacitating heat release (or untenable condition). Evidently incapacitation is the combinatory effect of heat, smoke asphyxiation and heart failures due to fear and panic (cumulative untenable conditions). It is assumed here that the prior knowledge given to passengers at boarding of the use of oxygen mask is sufficient to make them overcome breathing problems but not heat effects. The time to migrate from seat positions to the exits being sufficiently small compared to the total evacuation time (see below). Incapacitation due to panic and fear are covered by the vulnerability level that is assumed by the group the passenger belongs.

Heat release rate (HRR) is energy per unit time and can either be measured experimentally or obtained by multiplying the mass loss rate by the heat of combustion. The most important input to a fire model is the HRR versus time curve and the fire spread. A stochastic differential expression can be derived based on experimental data performed by Bukowsk et al [9] for selected passenger train materials. Some of the materials are the same as those for aircrafts. The peak HRR in the investigation varied over an order of magnitude from 65 kW/m2 for the graphite foam to 745 kW/m2 for the wall fabric. The majority of the 34 individual sample materials tested had peak HRR between 100 and 600 kW/m2. These are guidelines in deriving expressions that randomly generates HRR depending on the material encountered. An expression covering twice the range of 150 to 1500 KW/m2 was used and the accumulation of heat and the effect until incapacitation recorded.

In this investigation, egress routes are represented by a graph, made up of nodes and edges. Nodes between an origin and a destination can be occupants seating positions, points of interest (location of properties or persons of interest) or of change of direction. Times to evacuate are assumed to be the time taken by an occupant to reach an exit from his or her seating position (origin). Total time to evacuate (T_r) will include time of recognition (T_B), time to respond and land (T_D) and time of egress (T_X) [8]. Usually time of recognition (T_B), for aircrafts, is small as most aircrafts have fire and or smoke warning systems. Response time (T_D) cannot reasonably be estimated as that depends on the nearest and adequate landing location. The total time (T_r) to evacuate is then a summation of these times given as

$$T_r = T_D + T_B + T_X \qquad (1)$$

where

T_r = Total evacuation time, without external intervention (min).
T_B = Recognition time (min).
T_D = Response and landing time (min).
T_X = Egress time (min).

All the above times can have distributions defined by hazard functions.

Recognition time and Response time are mainly attributed to the pilot’s activities, being not in the control of the passengers. Recognition can be communicated information from crew, passenger or device. Where there is information or data and certainty of the same, these will be described by their representative function. To overcome the unavailability of data for the input parameters is to take them as random variables having values in a defined state space. For defined route, reasonable estimates could be made for the response and landing time. In such a case the Recognition time (T_B), the Response and landing time (T_D) could be approximated by a distribution function. In this simulation, the above equation was modified so that the Recognition and response time (T_D and T_B) was assumed to be a constant which simplified the equation as shown below.

$$T_r = K + T_X \qquad (2)$$

Where

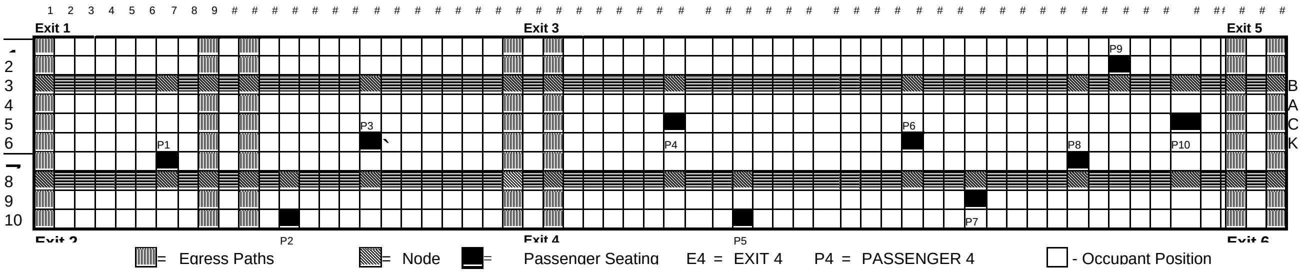
K = Constant, summation of T_D and T_B, assumed to be 20 minutes in the simulation below.

T_X will be the focus of this modeling since a constant value can be added for the other component. The simulation takes into account situations when the exit is inaccessible or unreachable due to an event like a disoriented passenger remaining at the exit. Such an event assumes an unreachable destination that takes up impossible values (infinity). While it is possible to represent the network by a graph; it is more normal to do so with a computer using a matrix representation.

4 Matrix Representation

The network so formed by nodes having virtual boundaries can be represented by a square matrix, say n x n, such that the *i*th row and *i*th column of the matrix correspond to the *i*th node. The diagonal elements are set to zero and the (*i,j*)th entry identifies the random variable attached to the directed edge starting at node *i* and ending at node j. It should be noted that the (*i,j*)th entry is not in general identical to the (*j,i*)th entry. If there is no directed arc between the nodes *i* and *j*, the (*i,j*)th entry is set to zero.

Table 2 SPACE NETWORK FOR THE AIRCRAFT



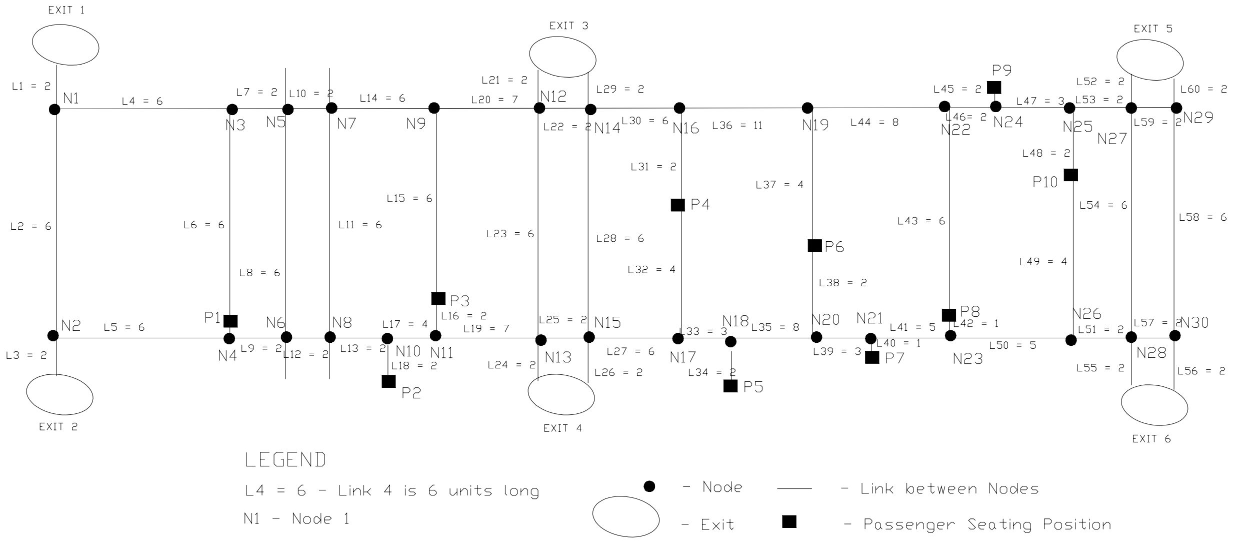


Fig 1. Network Representation and Configuration

The representative matrix of the above table is shown below

$$\begin{pmatrix}
0000000000 & 0000000000 & 0000000000 & 0000000000 & 0000000000 & 0000000000 & 0 \\
0000000000 & 0000000000 & 0000000000 & 0000000000 & 0000000000 & 0090000000 & 0 \\
0000000000 & 0000000000 & 0000000000 & 0000000000 & 0000000000 & 0000000000 & 0 \\
0000000000 & 0000000000 & 0000000000 & 0000000000 & 0000000000 & 0000000000 & 0 \\
0000000000 & 0000000000 & 0000000000 & 0400000000 & 0000000000 & 0000010000 & 00 \\
0000000000 & 0000003000 & 0000000000 & 0000000000 & 0060000000 & 0000000000 & 0 \\
0000001000 & 0000000000 & 0000000000 & 0000000000 & 0000000000 & 0008000000 & 0 \\
0000000000 & 0000000000 & 0000000000 & 0000000000 & 0000000000 & 0000000000 & 0 \\
0000000000 & 0000000000 & 0000000000 & 0000000000 & 0000070000 & 0000000000 & 0 \\
0000000000 & 0020000000 & 0000000000 & 0000500000 & 0000000000 & 0000000000 & 0
\end{pmatrix}$$

The adjacency matrix for the passengers are as presented below. A node that is passable is identified with a ‘1’, otherwise it is a ‘0’. The ten arbitrarily chosen positions of the passengers are identified as before from 1 to 10.

$$\begin{pmatrix}
1000000010 & 1000000000 & 0001010000 & 0000000000 & 0000000000 & 0000000010 & 1 \\
1000000010 & 1000000000 & 0001010000 & 0000000000 & 0000000000 & 0090000010 & 1 \\
1111111111 & 1111111111 & 1111111111 & 1111111111 & 1111111111 & 1111111111 & 1 \\
1000001010 & 1000001000 & 0001010000 & 0100000000 & 0010000000 & 1000010010 & 1 \\
1000001010 & 1000001000 & 0001010000 & 0400000000 & 0010000000 & 1000010001 & 01 \\
1000001010 & 1000003000 & 0001010000 & 0100000000 & 0060000000 & 1000010010 & 1 \\
1000001010 & 1000001000 & 0001010000 & 0100000000 & 0010000000 & 8000010010 & 1 \\
1111111111 & 1111111111 & 1111111111 & 1111111111 & 1111111111 & 1111111111 & 1 \\
1000000010 & 1010000000 & 0001010000 & 0000100000 & 0000070000 & 0000000010 & 1 \\
1000000010 & 1020000000 & 0001010000 & 0000500000 & 0000000000 & 0000000010 & 1
\end{pmatrix}$$

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The distance table for the various passenger seating positions to the respective exits is presented below. This can be represented for simulation by a three-dimensional (nxnxn) matrix.

Table 2: Distances of passengers from the respective exits

DISTANCES OF PASSENGERS TO EXITS

EXITS

		1				**2**				**3**				**4**				**5**				**6**			
		D1	***D2***	***D3***	***D4***	***D1***	***D2***	***D3***	***D4***	***D1***	***D2***	***D3***	***D4***	***D1***	***D2***	***D3***	***D4***	***D1***	***D2***	***D3***	***D4***	***D1***	***D2***	***D3***	***D4***
P	**1**	25	38	40	48	20	40	58	∞	58	63	∞	∞	50	55	70	∞	143	148	155	153	140	160	∞	∞
A	**2**	58	∞	∞	∞	43	58	63	∞	53	55	58	60	38	43	70	75	145	150	∞	∞	125	130	155	160
S	**3**	55	60	∞	∞	50	70	∞	∞	28	33	∞	∞	28	33	∞	∞	115	120	130	135	120	125	∞	∞
S	**4**	90	98	∞	∞	90	95	∞	∞	28	33	38	∞	28	33	48	53	78	83	88	93	78	83	88	93
E	**5**	113	∞	∞	∞	98	128	∞	∞	48	53	∞	∞	40	60	∞	∞	85	90	∞	∞	70	75	95	100
N	**6**	118	128	∞	∞	118	128	∞	∞	67	72	77	82	53	58	63	68	53	58	63	68	50	55	75	80
G	**7**	138	∞	∞	∞	120	145	∞	∞	73	165	170	∞	55	60	178	188	53	58	∞	∞	38	43	95	100
E	**8**	143	148	∞	∞	135	155	∞	∞	75	80	85	130	70	90	75	95	33	38	43	∞	28	33	48	53
R	**9**	138	163	200	205	155	178	198	∞	75	80	175	180	155	160	175	180	20	25	∞	∞	38	43	∞	∞
S	#	150	158	∞	∞	153	158	∞	∞	83	88	98	103	85	90	95	100	18	23	33	38	20	25	30	35

D2 = Distance 2 ∞ = Infinity = 1000

The positions occupied by the passengers can be represented by a matrix according to the configuration shown above in Table 2.

5. HAZARD FUNCTION

The hazard function, h(x), is the probability that a component will fail (or that an event will take place) between times t and t+dt given that it hasn't already failed (or happened). It represents the instantaneous death rate for an individual surviving to time t. The hazard function is also known as the failure rate, hazard rate, or force of mortality, h(x) is the ratio of the probability function P(x) to the survival function S(x), given by

$$h(x) = \frac{P(x)}{S(x)}$$

$$= \frac{P(x)}{1 - D(x)},$$

where D(x) is the distribution function [2].
It is given as

$$D(x) = P(X \le x) \equiv \int_{-\infty}^{x} P(x)\,dx.$$

Hazard plots are most commonly used in reliability applications.

The cumulative hazard function is the integral of the hazard function. It can be interpreted as the probability of failure at time x given survival until time x.

$$H(x) = \int_{-\infty}^{x} h(\mu)d\mu$$

This can alternatively be expressed as

$H(x) = -\ln(1 - F(x))$ *H(x)* satisfies the following conditions $h(x) \ge 0, \quad for\ all\ x$ and

$$\int_{0}^{\infty} h(x)\,dx = \infty$$

Survival functions are most often used in reliability and related fields. The survival function is the probability that the variant takes a value greater than x.

$$S(x) = Pr[X > x] = 1 - F(x)$$

5.1 DISCRETE HAZARD FUNCTION

The hazard function is generally defined only for continuous distributions. The discrete hazard function is relevant for most practical purpose. The Weibull and exponential distributions, and the Kaplan-Meier Nonparametric Survival function estimation are typical lifetime distributions used in hazard simulations. Others hazard functions include the gamma or lognormal and that used by Hasofer and Odigie [5]. The hazard function can either be said to be increasing or decreasing depending on if the unit is deterioration or improving with age. The choice of the distribution function used depends on the phenomenon being described and its relevance. In choosing a hazard function for this simulation, consideration is given to the general shape of fire life cycle graphs, the type of fire most likely, the HRR, and the spatial distribution of the far fuel load that enhances spread. The general shape of fire lifecycle is exponential at the development stage that remains approximately constant at maturity followed by a negative exponential for the decaying segment. The spatial distribution of the main fuel (seats) enables spotting and spread, the seats being close enough to be ignited by an adjacent one on fire.

Examples

(1) A decreasing order discrete hazard function follows.

Let x be a positive number (say 2) and Let X be a discrete random variable with probability function $P(X = n) = p_n$, ($n = 0, 1, 2, \ldots$). Let $p_n = x$ for $a \le n \le a + b$, $a = 2$ and zero elsewhere; a = 2, b = 14, and that

$$h_n = \frac{e^{-2x}}{1 + 0.5(n - a)e^{-2x}} \qquad (2)$$

where $h_n = 0$ for $n < a$ and $n > a + b$.

(2) An increasing order discrete hazard function

Let a, b be two positive integers and let x be a positive number such that $(b + 1)\,x \le 1$. Let as before X be a discrete random variable with probability function $P(X = n) = p_n$, ($n = 0, 1, 2, \ldots$). Let $p_n = x$ for $a \le n \le a + b$ and zero elsewhere. In other words, we take X to be uniformly distributed over the integers from a to $a + b$. It is then easy to check that $h_n = 0$ for $n < a$ and that

$$h_n = \frac{x}{1 - (n - a)x} \qquad (3)$$

For $a \le n \le a + b$.

For X not to be defective we must have $x = 1/(b + 1)$. In that case, $h_n = 1$, for $n > a + b$. Otherwise, $h_n = 0$ for $n > a + b$.

(3) For the same conditions as in (2) above but for $0 \le x \le 1$ another increasing order discrete hazard function is

$$h_n = \frac{n!}{(a - x)\,x^n} \qquad (4)$$

giving the graphs below. This was used for the simulation.

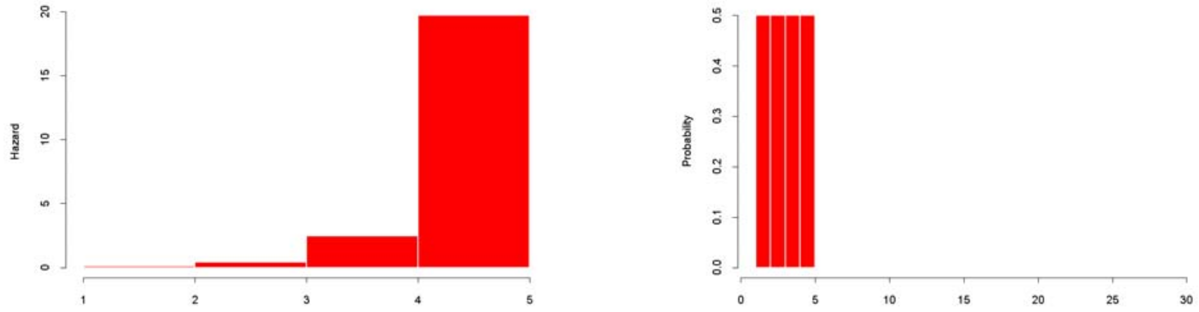

Fig 2 (a) Hazard function (b) Probability function

6. THE SIMULATION

The objective of the simulation is to determine the probabilities of the time distribution of occupants egress under distress conditions. The choice of an exit can be any of the exits as long as there is a path to it. The nearest exit is the first to be considered. Alternative paths can be taken if and only if the chosen exit becomes unreachable for any of many reasons. For such the next nearest exit is selected. This can repeat itself until a reachable exit is found or untenable condition is reached at the current node or at the chosen exit. For each run the category the passenger belongs is randomly chosen and the hazard function is used to determine the next level of hazard. The corresponding speed hence the time to transit the distance to the next node is recorded. The simulation keeps record of the egress history of each of the V nodes, the time to egress, spread of fire and untenable condition is obtained. As egress progresses and at any node where exits are equidistant, a Bernoulli trial is performed to determine the next adjacent node in the path towards the exit with a success. If say node j has been reached a Bernoulli trial with probability of success $h_{ij}\ (T_r)$ is carried out. $h_{ij}\ (T_r)$ is the corresponding hazard value from the hazard matrix. If the outcome is a success j is reached in time T_r; where T_r is the time corresponding to j in the time matrix. From this information the time required to evacuate all occupants in the aircraft can be determined.

To effect delays due to unforeseeable circumstance, and by other passengers, waiting time is introduced at random intervals and at collisions. A delay is a positive number. The next event may or may not occur. Non-occurrence takes the value of infinity, ∞. Hence time T to transit to the next node is assigned the symbol ∞. For such a random variable, we have

$$\lim_{x \to \infty} P(W \le x) \quad = \quad p \tag{5}$$

with $p < 1$.

For all practical purpose in this simulation a large number (say 1000) is assigned to T to represent infinity, ∞ .

The flow chart for the computer simulation is as shown in figure below

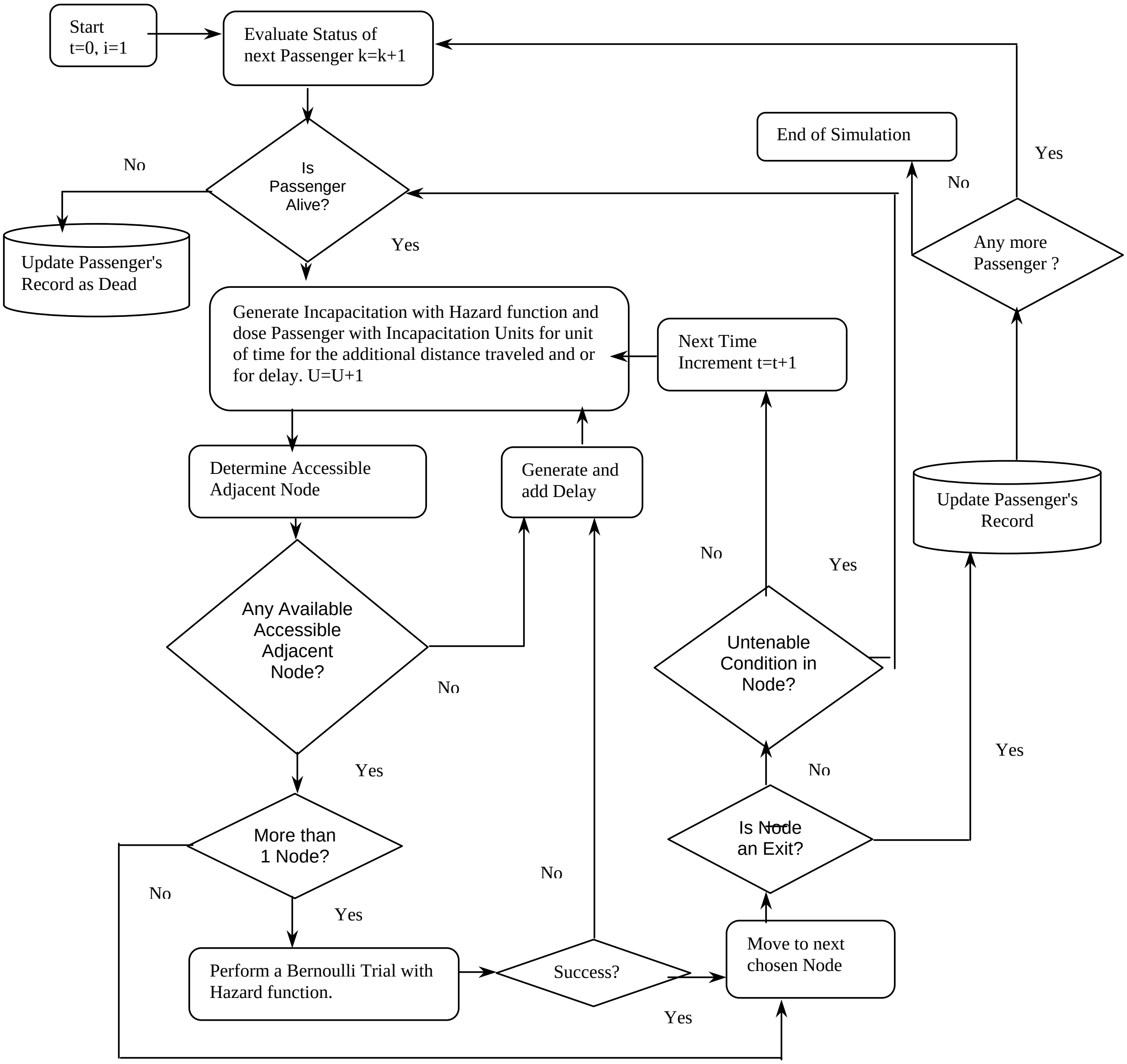

Fig 3 Flowchart of the simulation

7. ILLUSTRATION

An example is set below to illustrate a typical simulation. Input data include the aircraft network configuration, the seating positions of a number of passengers (10 as shown in the figure above), source of fire as from the right engine, and hazard function of the fire represented as incapacitation units of emission.

	MINIMUM DISTANCES TO EXITS (ft)									
	P	A	S	S	E	N	G	E	R	S
Exits	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	25	58	55	90	113	118	138	143	138	150
2	20	43	50	90	98	118	120	135	155	153
3	58	53	28	28	48	67	73	75	75	83
4	50	38	28	28	40	53	55	70	155	85
5	143	8	115	78	85	53	53	33	20	18
6	140	125	120	78	70	50	38	28	38	20

As there is no sufficient data to use we shall assume the following:

The higher the group level of an occupant the less the ability to withstand adverse conditions that lead to untenability, requiring a lower number to incapacitation. Significant research is required to obtain enough data that defines untenable conditions for the respective groups as defined above. Furthermore, the combinatory effect of both fire and smoke on humans needs further investigation. We shall assume the following describes untenability:

Table 3 Group Untenable Conditions

	GROUPS			
	1	**2**	**3**	**4**
U	350	300	250	200

U = Utenable Condition

It is given that a passenger's exposure to the adverse conditions is at an increasing rate if the direction of egress is towards the source of fire and at a decreasing rate if otherwise.

8. RESULTS

The following output of the simulation gives the probability of survival for the respective passengers.

Table 4 Passengers' Probability of Surviving

	PASSENGERS									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Probability (%)	100	99.9	99.5	85.7	92.6	99.1	99.9	96.9	99.5	90.1

A typical output of the simulation, say for the 970th run, follows:

Table 5

		Exit taken	Last Node Before Exit	Distance Travelled (ft)	Time to Travel (secs)	Accumulated Incapacitation Units	Survival Status
P	1	1	1	27	30	35.99	0
A	2	4	13	31	58	100.50	0
S	3	1	1	26	22	26.06	0
S	4	5	27	30	67	120.98	0
E	5	4	15	13	5	8.91	0
N	6	3	14	27	68	103.09	0
G	7	5	27	50	105	189.00	0
E	8	5	27	28	62	112.49	0
R	9	5	27	9	8	14.36	0
	10	0	17	17	116	210.37	1

Refer to Fig 1

A successful egress has Survival status = 0

An unsuccessful egress has an exit number = 0

Table 6 Cumulative Density Function for Passenger 4

```
        y    z   cdf
 [1,]   0 0.000 0.000
 [2,]  15 0.159 0.159
 [3,]  30 0.159 0.318
 [4,]  45 0.116 0.434
 [5,]  60 0.164 0.598
 [6,]  75 0.111 0.709
 [7,]  90 0.097 0.806
 [8,] 105 0.076 0.882
 [9,] 120 0.055 0.937
[10,] 135 0.028 0.965
[11,] 150 0.017 0.982
[12,] 165 0.013 0.995
[13,] 180 0.002 0.997
[14,] 195 0.003 1.000
```

The possible values of the times to egress for passenger 4 are shown in the first column (y). The probability of exiting in these respective times is in the second column. Column three is the cumulative distribution function (cdf) given by

$$F(\chi) = P(T \le \chi) \qquad (6)$$

for the times of exiting. The probability of the time (T) that falls in an interval or that it is an integer can be obtained from the corresponding graph shown below.

$$P(a < T \le b) = F(b) - F(a) \qquad (7)$$

The corresponding histogram and cumulative distribution function for the above are shown below.

More details from the simulation for this particular passenger can be obtained from the output in Table 4 above. The probability of surviving for passenger 4 is 85.7%. It is worth noting that the figures on the left are times for surviving and the corresponding probabilities.

The simulation can also provide the same information for the other passengers.

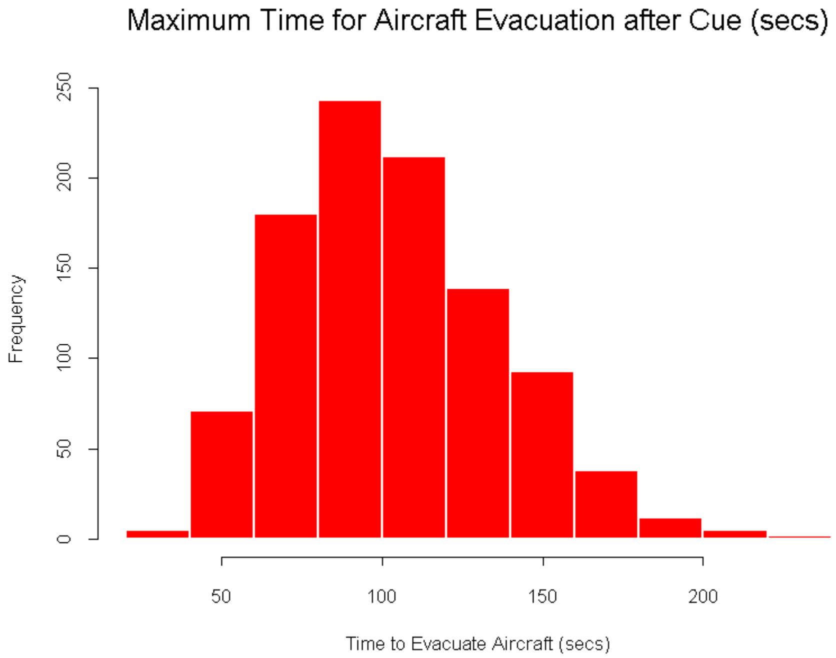

Fig 4 Histogram of the Time to egress for the passengers after the cue.

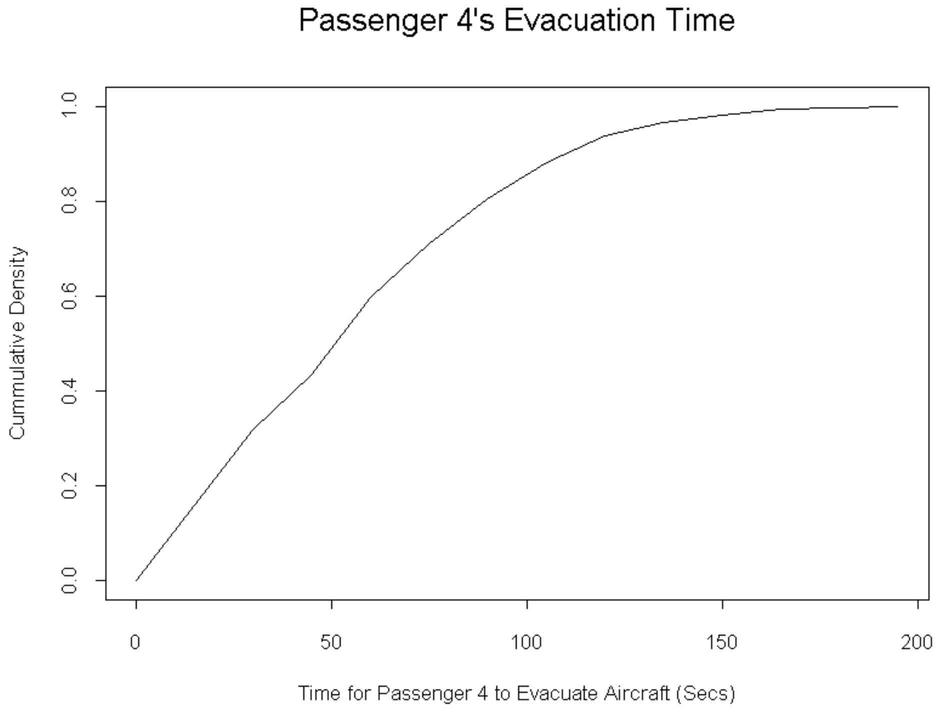

Fig 5 Cumulative Density function of the time to egress

Fig 5 above shows the cumulative frequency distribution of the time to evacuate for passenger 4 after receiving the cue. The same can be obtained for the other passengers and for the entire evacuation process.

9. DISCUSSION

The results show the probability of evacuating the aircraft for survivals. The simulation incorporated the delays due to several reasons including the clogging of exits or the orifice effect. This was achieved by stochastically obtaining estimates from the log normal distribution. Of significance is the ability to estimate the probabilities of egress for the respective passengers. Table above shows the probabilities of survival for the respective passengers. The 10th passenger being closer to the source of fire has lower survival probability. As expected the influence of the delays means the probabilities are not proportional to the distance from the fire source. The histogram in Fig above shows the maximum egress times for the survivals only taking into account that the times for the non-survivals is infinity. The influence of other variable that pertains to the structure or configuration of the aircraft can now be factored in. For instance, the influence of the number of exits on the evacuation can be modelled. Similarly the arrangement of the seats hence the respective distances of the passengers to the exits can also be investigated. The histogram in Fig shows the relative frequency of occurrence of times of egress for the entire evacuation process. We have dealt with a simplified example. It is possible to incorporate many other factors including:

External intervening factors:

1. fire brigade
2. exhaust systems

The broad coverage of this method of simulation will be relevant to effectively capturing the multi-various problems of incorporating so many indeterminate factors. The factors that have been addressed in this simulation include: (a) the number of passengers, (b) the number of exits, (c) the configuration of the aircraft that defines the paths, (d) the diversity of the types of passengers that may board the aircraft, (e) the delays due to undefined reasons including conflicts and different rates of migration, and (f) the opportunity to choose any of the exits as the egress eventuates. These are all variables that can take on a number of values.

Part of the output shown in Table above gives the details per run for the passengers. This includes the last exit reached before exiting or succumbing to untenable condition, the last node reached exiting for the survivals, the total distance travelled to the point of determination, the total time to get there, the accumulated incapacitation, and the status of the passenger (0 for survival and 1 for non-survival).

For a given aircraft it is now possible to estimate the time for evacuating all categories of occupants within certain level of confidence.

9.1 DEPENDENCY

Due to the extensive nature of this modeling, passenger dependency was left out. To incorporate dependency additional groups need to be created. For instance, a passenger assisting another will result in a combined reduced speed and possibly more delays. The probability of exiting for the new group is the joint probability of the participating groups.

10 SUMMARY

Without historical data of egress time, incapacitation and untenable conditions for given aircraft configuration, it is difficult to provide definite estimates of the probabilities of survival or otherwise of passengers. The most appropriate methodology that will cover all possibilities is to stochastically generate variables from the state parameter of any variate of interest from the appropriate distribution. Where a relevant distribution is unavailable the hazard distribution function has been found to be appropriate allowing modifications as the process enfolds. A relatively large coefficient of variation should be used for the lack of real experimental data. Coefficient of variance of say 75% might be sufficient for the lack of statistical data. An attempt has been made here to define and implement a procedure of evaluation of these in a field of insufficient record. The flexibility of the method used allowed the incorporation of many variables that influence the process of evacuation. This investigation has highlighted the areas where relevant data are not available; also areas for further investigation. From this simulation reasonable estimates can be derived for management, safety, insurance, assurance and aircraft developmental purpose.

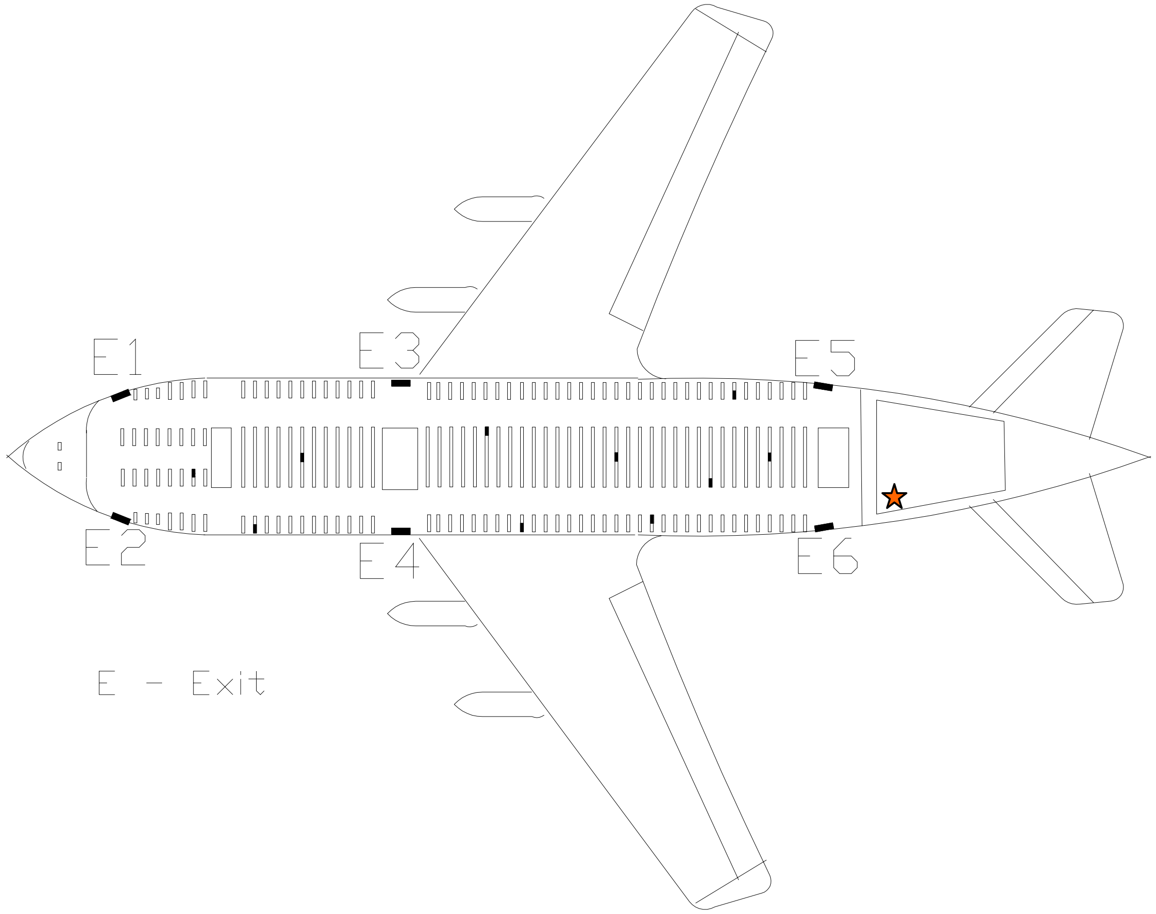

Fig 6 Aircraft Seating and Exit Locations

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