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BOEING 737 NEXT GENERATION COMMERCIAL JET AIRCRAFT ACCIDENT ANALYSIS

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Abstract

The Boeing 737 Next Generation series, comprising the 737-600, 737-700, 737-800, and 737-900 models, has been a widely used commercial jet aircraft since its introduction in the late 1990s. Although it is considered one of the most reliable aircraft in its class, it has unfortunately been involved in several accidents over the years. The hull loss aircraft accident concerning the Boeing 737 Next Generation, was statistically evaluated. Modes of aircraft movement indicators were developed and found to have a high relationship with aircraft accidents, and therefore could be considered a good accident risk indicator with R^2 higher than 0.8573. This means that the modes of aircraft movement indicators, when used to evaluate the hull loss aircraft accidents involving the Boeing 737 Next Generation, showed a high correlation with the occurrence of accidents. The relationship was found to be strong, with the R2 value being higher than 0.8573. This statistical evaluation suggests that the modes of aircraft movement indicators can be considered as reliable accident risk indicators for the Boeing 737 Next Generation. The high R2 value indicates that these indicators have a strong predictive ability in identifying the potential for accidents to occur.

Keywords: Commercial Aircraft, Aircraft Accident, Boeing 737 Next Generation, Risk Indicator

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Introduction

Aircraft accidents are costly and produce disastrous effects on the stakeholders in aviation industries. Rules and regulations have been developed and issued for aircraft safety (Cusick et al., 2017). Aircraft manufacturing companies have dedicated an enormous number of resources in research and technology development for aircraft safety (Boeing Commercial Airplanes, 2017; Airbus, 2022). Most aircraft operators currently have a good pilot recruitment and training program (Gosling et al., 2003). However, the aircraft accident is still happening and the research papers about aircraft accident appear minimal. This paper is a result of a statistical analysis of global aircraft hull loss accident based mainly on the Aviation Safety Network database (Aviation Safety Network, n.d.) as well as other sources.

Literature Review

The Boeing 737 Next Generation Commercial Jet Aircraft, commonly abbreviated as Boeing 737 Next Generation or, 737NG, is a narrow-body aircraft powered by two jet engines and produced by Boeing Commercial Airplanes (Boeing, n.d.). Launched in 1993 as the third-generation derivative of the Boeing 737. Boeing 737 Next Generation is the -600/-700/-800/-900 series of the Boeing 737 commercial jet aircraft. The Boeing 737 Next Generation has been produced since 1997. In November 2023 Boeing 737 Next Generation is manufactured 7,107 aircraft.

The accident process and the importance of human factors was explained with "Swiss Cheese" theory by Reason (1990). The Human Factors Analysis and Classification System (HFACS) was used (Wiegmann & Shappell, 2003). It seemed, however, that further study and more continual development are still needed. While the accident process and HFACS are useful the "back to the fundamental approach" is still necessary.

In Swiss Cheese theory, layers of defense lie between hazards and accidents. These layers of defense represent human efforts of accident prevention. Flaws can exist in each layer of defense in relative positions with respect to other layers. When these flaws lie up just right, they can cause accidents. So, an accident can happen even while defenses are in place. Reason hypothesizes that most accidents can be traced to one or more of four levels of failure: Level A: Organizational influences, Level B: Unsafe supervision, Level C: Preconditions for unsafe acts, and Level D: The unsafe acts themselves.

In Human Factors Analysis and Classification System (HFACS), Scott Shappell and Doug Wiegmann expand the Swiss Cheese theory by describing human error at each level of failure. The HFACS framework of human error is organized as follow.

Level A: Organizational influences, human errors occur in the following processes: 1) Resource management, 2) Organizational climate, and 3) Organizational process.

Level B: Unsafe supervision, human errors are results of 1) Inadequate supervision, 2) Planned inappropriate operations, 3) Failed to correct problems and 4) Supervisory violations.

Level C: Preconditions for unsafe acts may exist due to the following:

1) Environmental factors including Physical environment, and Technological environment.

2) Condition of operators including Adverse mental state, Adverse physiological state, and

- Physical/mental limitations.

3) Personal factors including Crew resource management, and Personal readiness.

Level D: The unsafe acts produce: 1) Errors including: Decision errors, Skill-based errors, and Perceptual errors, 2) Violations of these kinds: Routine, and Exceptional.

Within each level of HFACS, causal categories were developed that identify the active and latent failures that occur. In theory, at least one failure will occur at each level leading to an adverse event. If at any time leading up to the adverse event, one of the failures is corrected, the adverse event will be prevented.

In this study, however, in the beginning we will not yet accept that human factors are the dominating effect on aircraft accident, but we will use the fundamental statistical approach, where trends are analyzed carefully with appropriate statistical techniques, and hopefully some interesting information can be drawn. Whenever appropriate, comparisons with the HFACS will be made.

Research Methodology

Due to their popularity and long recorded flight operation since 1997, Boeing 737 Next Generation aircraft appear to be the case that should be studied in more detail. In this paper the commercial jet aircraft in Boeing 737 Next Generation were brought into consideration.

The frequency of accidents may vary with time. There could be many variables involved including aircraft aging, outdated technology, lacking pilot judgement and decision making, adverse weather, deficiency in communication and maintenance system and so on (International Civil Aviation Organization, 2015). If the number of aircraft used and aircraft aging were the dominating factors of the accident causes, one would expect the annual frequency of aircraft accidents to increase with the number of aircraft used and hence the time. However, if the improvement of technology, pilot and supporting personnel training and other factors were the dominating factors, the frequency rate of aircraft accident could decrease with time (EUROCONTROL, 2021).

The framework analysis of this study is collecting the data from Boeing 737 Next Generation hull loss accident and developing mathematical model from flight phase of aircraft accident. Modes of aircraft movement indicators were developed and analyzed the relationship with aircraft accidents to evaluate the hull loss aircraft accidents involving the Boeing 737 Next Generation (Brockwell & Davis, 2016; Montgomery et al., 2015).

Boeing 737 Next Generation Hull Loss Accident Data Collection

The author collected the data from the Boeing 737 Next Generation hull loss accident from the first Boeing 737 Next Generation hull loss accident in July 2006 until the accident in 2022. A total of 26 Boeing 737 Next Generation hull loss accident cases is presented in Table 1. They are to be studied and analyzed in this paper.

The purpose of the study is to analyze the patterns and trends in Boeing 737 Next Generation hull loss accidents over the years. To collect the data, the author referred to official reports from aviation authorities, accident investigation reports, news articles, and other credible sources. The data collected includes information such as the date of the accident, location, flight details, number of fatalities, probable cause of the accident, and any relevant findings from accident investigations.

The 26 hull loss accidents involving Boeing 737 Next Generation aircraft were carefully studied and analyzed to identify any common factors or trends. The author looked for patterns in terms of the causes of accidents, potential technical issues with the aircraft, human factors, and any other relevant factors.

Table 1 Hull loss accidents on Boeing 737 Next Generation from 2006 to 2022

No.	Date	Type	Registration	Operator	Fatality	Damage	Location	Movement
1	28-Jul-10	Boeing 737-7L9 (WL)	TS-IEA	Mauritania Airways, lsf Tunis Air	0	Substantial	Conakry International Airport (CKY) (Guinea)	Landing
2	16-Aug-10	Boeing 737-73V (WL)	HK-4682	AIRES Colombia	2	Destroyed	San Andres Island-Gustavo Rojas Pinilla Airport (ADZ/SKSP), Colombia	Landing
3	22-Jul-13	Boeing 737-7H4 (WL)	N753SW	Southwest Airlines	0	Substantial	New York-La Guardia Airport, NY (LGA) (United States of America)	Landing

No.	Date	Type	Registration	Operator	Fatality	Damage	Location	Movement
4	17-Apr-18	Boeing 737-7H4 (WL)	N772SW	Southwest Airlines	1	Substantial	105 km (65.6 mls) NW of Philadelphia, PA (United States of America)	En route
5	29-Sep-06	Boeing 737-8EH	PR-GTD	Gol	154	Destroyed	30 km (18.8 mls) from Peixoto Azevedo, MT (Brazil)	En route
6	05-May-07	Boeing 737-8AL	5Y-KYA	Kenya Airways	114	Destroyed	5,5 km (3.4 mls) SE of Douala Airport (DLA) (Cameroon)	En route
7	20-Aug-07	Boeing 737-809	B-18616	China Airlines	0	Destroyed	Okinawa-Naha Airport (OKA) (Japan)	Landing
8	10-Nov-08	Boeing 737-8AS (WL)	EI-DYG	Ryanair	0	Substantial	Roma-Ciampino Airport (CIA) (Italy)	Landing
9	25-Feb-09	Boeing 737-8F2	TC-JGE	THY	9	Destroyed	1,5 km (0.9 mls) N of Amsterdam-Schiphol International Airport (AMS) (Netherlands)	Approach
10	22-Dec-09	Boeing 737-823 (WL)	N977AN	American Airlines	0	Destroyed	Kingston-Norman Manley International Airport (KIN) (Jamaica)	Landing
11	25-Jan-10	Boeing 737-8AS (WL)	ET-ANB	Ethiopian Airlines	90	Destroyed	11 km (6.9 mls) SW off Beirut International Airport (BEY) (Lebanon)	Initial climb
12	22-May-10	Boeing 737-8HG (WL)	VT-AXV	Air India Express	158	Destroyed	Mangalore-Bajpe Airport (IXE) (India)	Landing
13	30-Jul-11	Boeing 737-8BK (WL)	9Y-PBM	Caribbean Airlines	0	Destroyed	Georgetown-Cheddi Jagan International Airport (GEO) (Guyana)	Landing
14	14-Oct-12	Boeing 737-8KN (WL)	TC-TJK	Corendon Airlines	0	Substantial	Antalya Airport (AYT) (Turkey)	Pushback
15	13-Apr-13	Boeing 737-8GP (WL)	PK-LKS	Lion Air	0	Substantial	Denpasar-Ngurah Rai Bali International Airport (DPS) (Indonesia)	Approach
16	19-Mar-16	Boeing 737-8KN (WL)	A6-FDN	flydubai	62	Destroyed	Rostov Airport (ROV) (Russia)	Approach
17	13-Jan-18	Boeing 737-82R (WL)	TC-CPF	Pegasus Airlines	0	Substantial	Trabzon Airport (TZX) (Turkey)	Landing
18	16-Aug-18	Boeing 737-85C (WL)	B-5498	Xiamen Airlines	0	Substantial	Manila-Ninoy Aquino International Airport (MNL) (Philippines)	Landing
19	01-Sep-18	Boeing 737-8AS (WL)	VQ-BJI	Utair	0	Destroyed	Adler/Sochi Airport (AER) (Russia)	Landing
20	28-Sep-18	Boeing 737-8BK (WL)	P2-PXE	Air Niugini	1	Substantial	0,5 km (0.3 mls) from Chuuk/Weno International Airport (TKK) (Micronesia)	Approach
21	03-May-19	Boeing 737-81Q (WL)	N732MA	Miami Air International	0	Substantial	Jacksonville Naval Air Station, FL (NIP) (United States of America)	Landing
22	01-Jul-19	Boeing 737-85R	VT-SYK	SpiceJet	0	Substantial	Mumbai-Chhatrapati Shivaji International Airport (BOM) (India)	Landing
23	21-Nov-19	Boeing 737-8F2 (WL)	TC-JGZ	THY	0	Substantial	Odessa-Central Airport (ODS) (Ukraine)	Landing
24	05-Feb-20	Boeing 737-86J (WL)	TC-IZK	Pegasus Airlines	3	Destroyed	Istanbul-Sabiha Gökçen International Airport (SAW) (Turkey)	Landing
25	07-Aug-20	Boeing 737-8HG (WL)	VT-AXH	Air India Express	21	Destroyed	Kozhikode-Calicut Airport (CCJ) (India)	Landing
26	21-Mar-22	Boeing 737-89P (WL)	B-1791	China Eastern	132	Destroyed	20 km (12.5 mls) SW of Wuzhou, Tengxian County (China)	En route

Mode of Aircraft Movement Indicators Development

It is now generally accepted that many factors are involved and cause an aircraft accident, and the relationship between these causes is complicated (Boeing Commercial Airplanes, 2017). From a study by Boeing on many types of commercial aircraft, flight phase or mode of aircraft movement seemed to be related to percentage of accident. We will try to gain a better understanding of the relationship between the number of accidents and various factors by using fundamental statistical analysis.

Later an empirical equation relating to some important relationships will be proposed. At this stage, the effect of mode of aircraft movement on Boeing 737 Next Generation would be investigated. The mode of aircraft movement was classified as pushing back, standing, taxiing, taking off, climbing, or ascending, enroute, approaching, descending, and landing.

For Boeing 737 Next Generation aircraft, the relationship between percentage of accident and mode of aircraft movement was represented by a diagram as shown in Figure 1.

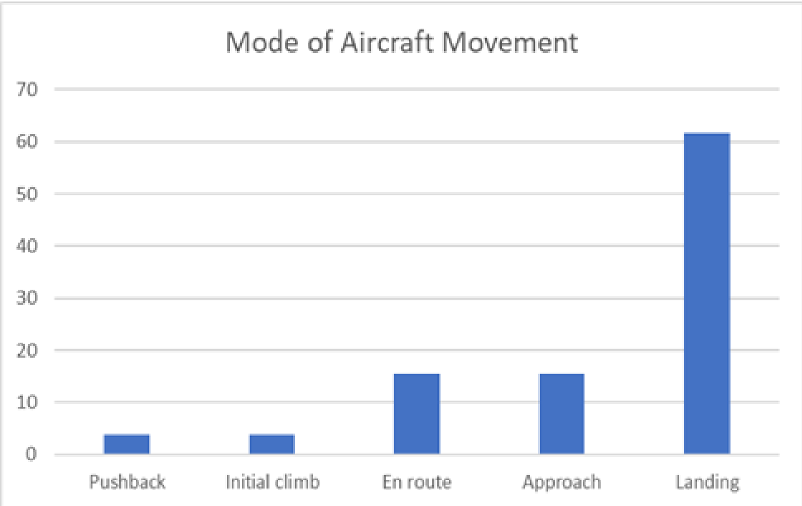

Figure 1 Percentage of Accident Cases Associated with Modes of Aircraft Movement

From the 26 Boeing-737 Next Generation hull loss aircraft accident cases with known accident information and modes of aircraft accident movement, most accident was found to occur at landing mode (61.53%), followed by approaching (15.38%), enroute (15.38%), initial climb (3.04%), and push back (3.04%). The higher percentage of accident cases implies that particular accident is more probable to happen. Therefore, percentage of accident cases represents the probability of accident, denoted by P_a. The value of probability obtained this way is not absolute because it depends on the number of accidents. However, the probability is valid relative to each movement mode.

Risk Indicator Mathematical Model Development

1) Mathematical Model Development: In this study, the relations between accidents and causes will be described numerically, not qualitatively, and statistics will be used to verify accuracy. Types of accidents are separated by modes of aircraft movement including pushing back, standing, taxiing, taking off, climbing, or ascending, enroute, approaching, descending, and landing, as described in Section 3.3 (Commercial Aviation Safety Team, 2013). Causes of accidents consist of multiple risk factors, including the media, altitude change, axial speed, and acceleration. The selection of these risk factors is based on an idea in an academic article in Boeing Commercial Airplanes (2017). Each risk factor is assigned an indicator, I_1 for media and environment, I_2 for altitude change, I_3 for axial speed, and I_4 for axial acceleration.

Likert Scale is applied to assign numerical value to risk factor indicators as shown in Table 2 (Likert, 1932). The higher the assigned number should relate to the higher the accident risk.

Minimum value of 1 is assigned to each indicator when associated risk factor is minimum. On the contrary, the maximum value of 5 is assigned to each indicator when the associated risk factor is maximum. Intermediate values are assigned according to the seriousness of risk factors. Table 2 shows assignment of Likert scale to all indicators (I_i's) and describes conditions that justify risk factors in each movement mode. A systematic number assignment was employed for each mode of aircraft movement in the development of I_1, I_2, I_3, and I_4 as summarized in Table 3.
The definition of flight phase or mode of aircraft movement by International Civil Aviation Organization was observed.

Table 2 Interpretation of Mode of Aircraft Movement

Factors that caused risk	**Indicators**	**Remark**	***Movement Mode***
Media and environment	$I_1 = 1$	On ground	*Pushing Back, Standing, Taxiing*
	$I_1 = 2$	Air	*En Route*
	$I_1 = 3$	Terrain/air interphase	*Climbing, Approaching*
	$I_1 = 4$	Ground/terrain/air interphase	*Taking Off, Landing*
Altitude Change	$I_2 = 1$	No change	*Standing, Taxiing, Pushing Back, en route*
	$I_2 = 2$	Up (in air/terrain interphase)	*Climbing*
	$I_2 = 3$	Up (in ground/terrain/air Interphase)	*Taking Off*
	$I_2 = 4$	Down (in air/terrain interphase)	*Approaching*
	$I_2 = 5$	Down (in ground/terrain/air Interphase)	*Landing*
Axial Speed	$I_3 = 1$	Near zero speed (on ground)	*Pushing Back, Standing, Taxiing*
	$I_3 = 2$	Low speed (in ground/terrain/air interphase).	*Taking Off, Landing*
	$I_3 = 3$	Low speed Flight (in air/terrain)	*Climbing,*
	$I_3 = 4$	Medium speed flight (in air/terrain interphase)	*Approaching*
	$I_3 = 5$	High speed flight (in air)	*En Route*
Axial Acceleration	$I_4 = 1$	Steady speed	*Standing, Taxiing, Pushing Back, en route*
	$I_4 = 2$	Acceleration	*Taking Off, Climbing*
	$I_4 = 3$	Deceleration	*Approaching*
	$I_4 = 5$	High deceleration	*Landing*

Table 3 Mode of aircraft movement and causal risk in Risk Indicators

Movement Mode	Media and environment I_1	Altitude Change I_2	Axial Speed I_3	Axial Acceleration I_4
Standing	1	1	1	1
Pushing Back	1	1	1	1
Taxiing	1	1	1	1
Taking Off	4	3	2	2
Climbing	3	2	3	2
En Route	2	1	5	1
Approaching	3	4	4	3
Landing	4	5	2	5

2) Risk Indicator Calculation: All indicators (I_i's) are combined to form a single numerical value of Risk Indicator (I_m) for each aircraft movement mode. The expression to combine I_i's into I_m is one of the main hypotheses of this study and initial proposal is to multiply all I_i's into I_m, as shown in equation.

$I_m = I_1 \ I_2 \ I_3 \ I_4$ (1)

2.1) The Value of Risk Indicator for landing

As an example, the value of I_m for landing (I_{m_ld}) was calculated from:

$I_{m\_ld} = (I_{1\_ld})(I_{2\_ld})(I_{3\_ld})(I_{4\_ld})$ (2)

And from the calculation of risk indicator I_{m_ld} or Risk indicator for landing movement mode is come from 4 x 5 x 2 x 5 equal 200

$I_{m\_ld} = 200$

2.2) The Value of Risk Indicator for approach

As an example, the value of Im for approach (Im_ap) was calculated from:

Im_ap = (I1_ap)(I2_ap)(I3_ap)(I4_ap) (3)

And from the calculation of risk indicator Im_ap or Risk indicator for approach movement mode is come from 3 x 4 x 4 x 3 equal 144

Im_ap = 144

2.3) The Value of Risk Indicator for enroute

As an example, the value of Im for enroute (Im_en) was calculated from:

Im_en = (I1_en)(I2_en)(I3_en)(I4_en) (4)

And from the calculation of risk indicator Im_en or Risk indicator for enroute movement mode is come from 2 x 1 x 5 x 1 equal 10

Im_en = 10

2.4) The Value of Risk Indicator for Climbing

As an example, the value of Im for Climbing (Im_clb) was calculated from:

Im_ clb = (I1_ clb)(I2_ clb)(I3_ clb)(I4_ clb) (5)

And from the calculation of risk indicator Im_ clb or Risk indicator for takeoff movement mode is come from 3 x 2 x 3 x 2 equal 36

Im_ clb = 36

2.5) The Value of Risk Indicator for Takeoff

As an example, the value of Im for takeoff (Im_toff) was calculated from:

Im_ toff = (I1_ toff)(I2_ toff)(I3_ toff)(I4_ toff) (5)

And from the calculation of risk indicator Im_ toff or Risk indicator for takeoff movement mode is come from 4 x 3 x 2 x 2 equal 48

Im_ toff = 48

Table 4 illustrates the aircraft movement modes and the result of risk indicators (I_m) from calculation in each aircraft movement mode.

Table 4 Risk Indicator (I_m) for Mode of Aircraft Movement

Movement Mode	I_1	I_2	I_3	I_4	I_m
Standing	1	1	1	1	1
Pushing Back	1	1	1	1	1
Taxiing	1	1	1	1	1
Taking Off	4	3	2	2	48
Climbing	3	2	3	2	36
En Route	2	1	5	1	10
Approaching	3	4	4	3	144
Landing	4	5	2	5	200

Research Results

Relation between Risk Indicator (I_m) and probability of accident (P_a) can be verified by curve fitting between I_m and P_a. Data of I_m for each movement mode is shown in Table 4 and data for P_a can be obtained from Figure 1. Both data for each movement mode are put together in Table 5.

Table 5 Probability of accident (P_a) and Risk Indicator (I_m) for each movement mode

Movement Mode	P_a	I_m
Standing		1
Pushing Back	3.04	1
Taxiing		1
Taking Off		48
Climbing	3.04	36
En Route	15.38	10
Approaching	15.38	144
Landing	61.53	200

Exponential function is selected as a form of relation between risk factor (I_m) and probability of accident (P_a). The first reason is because exponential function ensures continuous increment of P_a with increasing I_m. It is a common sense that higher risk leads to more accidents. The second reason is the rate of increment of exponential function also increases with value of independent variable, or $\frac{de^x}{dx} = e^x$. This characteristic matches data in Table 5 where probability of landing accident is very high, and landing risk indicator is also quite high relating to values in other movement modes.

The probability of accident (P_a), which is expected to relate to accident risk indicator (I_m), was plotted against I_m as shown in Figure 2. Empirical equation (5) was obtained from exponential curve fitting between I_m and P_a as follows:

$$P_a = 4.322\, e^{0.0115\, I_m} \quad (5)$$

R^2 for goodness of curve fitting by equation (5) was 0.8573 which is considered a "significant" fit ($R^2 > 0.7$). It seemed that equation (5) which was exponential and fitted well to the data was a satisfactory representation of the risk of accident based on mode of aircraft movement.

At this stage we were able to estimate the risk of an accident occurrence by using equation (5). In the next step of investigation, the severity of accident concerning Boeing 737 Next Generation of aircraft will be brought into consideration.

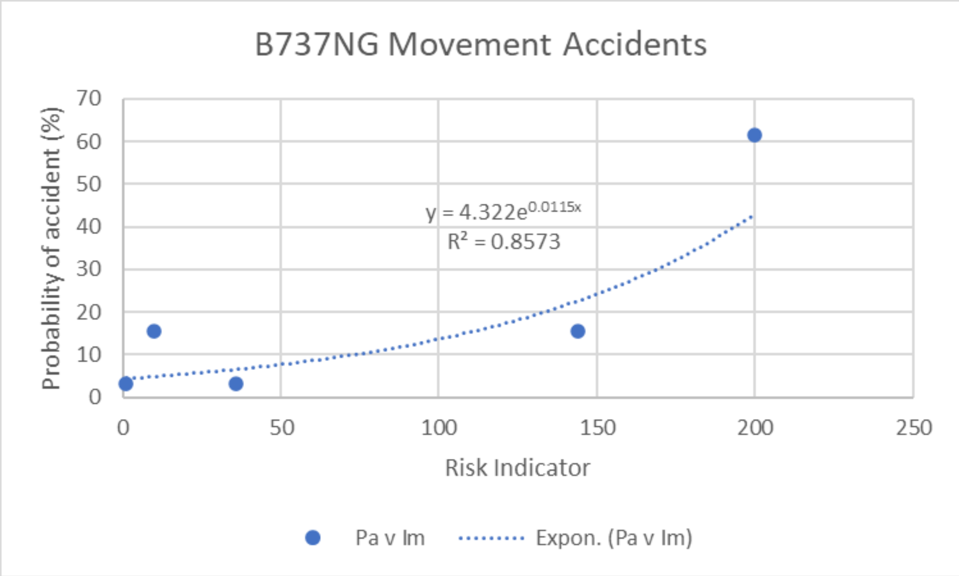

Figure 2 Exponential Relationship between P_a and I_m for Boeing 737 Next Generation

Conclusions and Discussion

The main hypotheses in this study are the value assignment of risk factor indicators (I_i's) as shown in Table 1, the expression to obtain risk indicator (I_m) from I_i's as shown in equation (1), and probability of accident prediction by I_m as shown by equation (5). These hypotheses are verified by value of R^2, or goodness of curve fitting, that came to 0.8574 in Figure 2. Therefore, values of factor indicators (I_i's), expression of risk indicator (I_m) and exponential prediction of accidents by I_m are adequate. Variations of these formulations may be experimented in future study.

It appeared that with newer technology reflecting in their newer models, less accident cases per thousand of aircraft delivered could be expected from Boeing 737 Next Generation aircraft. Pilot and machine error almost equally dominated the causes of accident. The risk indicator (I_m) of aircraft movement was related to the probability of accident such that it can be used to determine risk.

This study shows that risk indicators (I_m) can help to determine the risk of hull loss accident, therefore there should be a way to reduce the risk. For example, axel acceleration (I_4) affects I_m more than axel speed (I_3) in a landing. There should be a landing procedure to reduce axel acceleration and accept higher axel speeds. Other procedures can be modified similarly to reduce risk.

Further study into the relation between probability of accident (P_a) and risk indicator (I_m) should include the causes of this relation or causes of the accidents. The following should facilitate identification of the causes.

1) Modifying Im to be more specific. Im consists of 4 risk indicators associated with 4 risk factors, i.e., the media, altitude change, axial speed, and acceleration. More risk factors should be included, such as speed ranges and weight ranges. This expansion may help to identify to causes of accidents.

2) Separating accidents into more specific types. Accidents included in this study are the ones that resulted in hull losses. The hull loss should be separated into losses due to fire, crash or system failures divided according to systems on the aircraft.

3) More data points are needed to accommodate more specific movement indicators and accident types but will better facilitate identification of accident causes. ICAO should be consulted to modify regulations for better data gathering.

This study is limited to just Boeing 737 Next Generation aircraft. The same study should expand to other aircraft types to determine if the relation in equation (5) is universal. A relation between accidents and some indicators always help to identify the accident causes.

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