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Advocating System Safety Concept in Preventing Airline Accidents

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Abstract

System safety was conceptualized by the aerospace industry in the late 1940s in the United States (U.S.). Traditionally, users of system safety applied analysis to identify operational hazards and subsequently provide countermeasures before or after an accident. Unfortunately, very few aviation safety researches from the airlines had utilized it to promote aviation safety. To enrich this knowledge and contribute interest from academia, this paper adopted the inductive techniques of system safety in analyzing airline accidents and recommending a countermeasure. The authors reviewed 189 final accident reports from the National Transportation Safety Board (NTSB) covering FAR Part 121 scheduled operations (dated between January 1999 and May 2004). The findings revealed ten (10) accident causes (direct hazards), namely Flight Operations, Ground Crew, Turbulence, Maintenance, Foreign Object Damage (FOD), Flight Attendant, Air Traffic Control, Manufacturer, Passenger, and the Federal Aviation Administration. A block-diagram model using a Fault Tree Analysis (FTA), a leading tool for system safety experts, was created followed by probability simulation of accidents, five (5) case studies and FTA reports aiming to demonstrate the usefulness of system safety techniques in promoting airline safety.

Introduction

Although the recovery of passenger volume is slow, air transportation industry is stably regaining its customers (Woodyard, 2004). For instance, regardless of the outbreak of Severe Acute Respiratory Syndrome (SARS), between late 2002 and early 2003 in Asia-Pacific region that had impeded passengers from traveling with airlines and substantially consumed airline's profits, passengers are now gradually rebuilding their confidence in air transportation due to the relief of pathological threat (Dennis, 2003; FAA, 2004; Lu, 2003). In the United States (U.S.), after the disastrous 9/11 terrorist attacks and consequently resulted in a massive economic loss (Archibold, 2001; Eisenberg, 2001; Kluger, 2001), federal government such as the Transportation Security Administration (TSA) and the Federal Aviation Administration (FAA), in cooperated with other countries, have imposed more advanced technologies and proactive measures to ensure aviation safety and airport security (Loy, July, 2003).

Historically, the U.S. Federal Aviation Administration (FAA) is responsible for fostering and encouraging civil air commerce and auditing aviation safety (Adamski & Doyle, 1999; Rollo, 2000; Wells, 1999). However, the FAA's "dual-mandate" responsibility has resulted in criticism regarding the lack of sufficient ability to accomplish safety surveillance (Carlisle, 2001; Carmody, 2001; Donnelly, 2001; Filler, 2001; Nader & Smith, 1994; Stout, 1999). Not surprisingly, the workload of the FAA was immediately increased due to the urgent need of anti-terrorism activities after 9/11. As a result, the U.S. TSA, a new branch of the Department of Transportation (DoT), was created in charge with transportation safety contemporarily centering on airport security and aviation safety nationwide. Along with the extremely tightened airport security and economic rebounds after 9/11, aircraft accidents still happened periodically due to human error and would continuously endanger our passengers (e.g., US Airways Flight 5481 in Charlotte, NC, on January 8, May 2003). Accidents indicate airlines' ineffectiveness in protecting their passengers; and at the same time, most operate under a marginal or zero profit environment (Lu, 2003). In this situation, how to be more cost-effect and safer is a critical challenge to airlines. A model assisting airline practitioners to promptly identify needed safety trainings would be very helpful.

Literature Review

Aviation safety is always an important research topic. During the past decade, several leading media reports—the *Wall Street Journal* (Dahl & Miller, 1996, July 24; Goetz, 1998) and *USA Today* (Stroller, 2000 March 13)—have tried to rank airline safety but solely focused on a single element: the accident rate. In addition to the reports from Dahl and Miller, Goetz, and Stroller, Bowen and Lu (2000) advocated the importance of measuring airline safety performance and suggested a more comprehensive model to report airline's safety performance. In 2001, Bowen and Lu initiated a new safety measuring mechanism―Aviation Safety Rating (ASR). This study compared ten (10) major airlines' safety performance based on four (4) categories―Enforcement Action, Accident Rate, Management Performance, and Financial Health―containing seventeen (17) selected safety factors (Bowen & Lu, 2001). In 2004, Bowen and Lu conducted a follow-up study focusing on individual factor's criticality as to that of an airline's overall safety performance. They reported the importance of selected safety factors using performance sensitivity (Sp) and defined Sp as: the percentage change of overall safety score due to the percentage change of a specific safety factor. Based on Sp calculation, a list of prioritized factors impacting safety performance was coined. The result showed that fatality rate, average fleet age, and accident rate were the three most critical factors affecting an airline's overall safety performance (Bowen & Lu, 2004a).

Although prior studies had proposed a tool for measuring airline safety performance, they had one thing in common: they did not discover the genuine causes of an accident that ultimately contributed to airline's safety performance. Meanwhile, the root factors/precursors of accident causes were not identified either. This situation opens a window for a further research. In this study, system safety technique was applied to compensate the knowledge gap.

System Safety Techniques

System safety was conceptualized by the aerospace industry in the late 1940s in the United States (US) (Vincoli, 1993). Traditionally, system safety experts in aerospace engineering applied systemic analysis to identify operational hazards and subsequently provide countermeasures before and after a mishap (Malasky, 1982; Roland, & Moriarty, 1990). System safety is defined, by Military Standard 882B, as "the application of engineering and management principles, criteria, and techniques to optimize safety within the constraints of operational effectiveness, time, and cost throughout all phases of the system life cycle" (Layton, 1989, p.1). System safety is an effective approach to identify potential hazards, provide countermeasures, and assess the outcome in relation to an operational system (Malasky, 1982; Roland, & Moriarty, 1990; Vincoli, 1993). As noted by Vincoli (1993), a countermeasure could be system re-modification, warning device, safety training, or regulatory change. System safety is a doctrine used to minimize risk, optimize safety, and maximize system's expected function (Layton, 1989; Malasky, 1982, Vincoli, 1993). Yet there are very few studies using system safety in promoting aviation safety regardless of the common application in the field of aerospace engineering, product manufacturing and design, environment hygiene, and medical system.

In medical safety field, Robert L. Helreich (2000) advocated the application of system safety's error management concept in medical practice. In his study, he first reviewed the origin of system safety stemmed from aerospace engineering and the usefulness of data management pertaining to hazard reduction. To accomplish hazard reduction, a well-managed database was the key player to prevent medical malpractices based on the statistical predication of the likelihood of a failure. Yet, solely addressing on the quantitative forecast, Helrireich's study did not provide any workable models or procedures that the industry could adopt and implement. In fact, Helreich's work was not the only application of system safety techniques in medical industry. Manon Croheecke and his research associates (1999) and William Hyman (2002) utilized the leading tool of system safety, the so-called Fault Tree Analysis (FTA), in evaluating potential hazards associated with new innovated medical devices before moving toward its production phase within a product's life cycle.

In aviation safety, military first launched system safety techniques to improve pilot training procedures. According to Diehl's cross-reference analysis upon 208 military accidents, the top three pilot errors leading to mishaps were: decision making, mission analysis, and situation awareness (1991). Human error was found to be the major cause leading to aircraft accidents in Air Force (Diehl, 1991). In Diehl's qualitative study, he discovered that the breakdown of cockpit communication/team performance or crew coordination had specifically constituted aircraft mishaps. As a result, a mandatory crew/cockpit resource management (CRM) training for aircrews was immediately in place. Diehl's study also used system safety techniques to suggest a modification of cockpit layout of Cessna Citation, a business jetplane. He implemented hazard/ergonomic analysis, and discovered that the cockpit control panel should be re-designed in order to eliminate possible confusions between operators and their environment. His study made a linkage from system safety analysis, accident investigation, hazard identification, to human factor, CRM training, and subsequently recommended the development of a user-friendly cockpit.

A recent study by Thom and Clariett (2004) was published in Collegial Aviation Review focusing on the applicability of job safety and task analysis, another essential tool of system safety. In their study, a basic concern of system safety analysis, namely job safety analysis, was closely interpreted and the layout of human-machine interface was emphasized. Using Risk Homeostasis Theory (RHT) of human behavior, their study helped identify potential hazards surrounding hangar, factory, or student workshop both internally and externally (Thom & Clariett, 2004). This study introduced aviation educators the genuine part of system safety from job safety, environmental factors, failure modes, human error, and hazardous categories and did bring significant interests to the aviation community.

The previous studies showed the importance and applicability of aerospace engineering's system safety techniques in promoting military flight safety, reducing medical service fault and malpractice, enhancing cockpit design, and identifying workshop hazards. Although system safety has been recognized by various industries in upgrading safety or reliability; unfortunately, a very small portion of the aviation research community had utilized system safety techniques to promote airline safety.

Research Focus

The Office of System Safety is the leading office in the FAA working on system safety researches. Based on the submitted safety reports from concerned individuals and other available means, the FAA's Office of System Safety has periodically conducted safety studies and conferences using system safety in the area of engineering design, navigation system, weather and turbulent, GPS, runway incursion, consumer safety guideline, and airport operational procedures. But the usage of system safety has been closely tied to engineering discipline (FAA Office of System Safety, n.d.). On the other hand, regardless of the available system safety engineering guidelines and presentations, safety handbooks for consumers, workshops for maintenance personnel, database containing raw data provided by the FAA, very few studies from the airline industry have been done to help enhance operational safety. In order to fulfill knowledge gap and further apply system safety in promoting commercial aviation safety, the implementation of this study was designed as the following four (4) stages: 1) identifying the causes/direct hazards leading to airline accidents, 2) discovering critical safety factors constituting the causes leading to an accident, 3) creating a accident prevention model using a selected system safety technique, and 4) providing case studies and reports showing the applicability of the selected system safety technique in commercial aviation safety by recommending training emphasis.

Research Techniques

To paint the picture for a comprehensive aviation safety programs by using system safety, this study first re-visited and analyzed government's accident reports and categorized the causalities behind each mishap. Fault Tree Analysis (FTA), one of the essential tools of system safety, was followed to identify accident factors in order to explain how the root factors and accident causes were interrelated. Five case studies applying FTA were provided in this study in order to address the merit of system safety for future accident prevention programs.

Fault Tree Analysis (FTA)

FTA is used to examine an extremely complex system involving various targets such as facility, operators, finance, reputation, or property within the domain of operation. It uses an inductive approach in conjunction with Boolean logic and failure probability that connects a series of events leading to the top-event, in this study, an airline accident (Roland & Moriarty, 1990; Vincoli, 1993). To accomplish a holistic view of an aviation system facing critical hazards, FTA tracks upstream and identifies causal factors that may lead to an accident or system failure (Brown, 1976). In addition, FTA will help researchers structure an advisory foundation (recommendation-basis) for developing a better accident prevention program from bottom-up (Brown, 1976; Malasky, 1982). The basic procedure of conducting FTA is suggested as follows: 1) identifying the top-event, 2) finding all contributory events from top-down, and 3) creating a full "fault tree" for analysis and recommendation (Roland & Moriarty, 1990; Vincoli, 1993). Because FTA may encompass possibly hundreds root factors underpinning accident causes, this study introduced a mini-FTA model that is sufficient to describe its usefulness in accident-prevention and safety training (Vincoli, 1993).

Documentary Review

Accident reports (between 1999 January – 2004 May) were retrieved from the U.S. NTSB Accident Docket Databases focusing on FAA FAR Part 121 scheduled U.S. air carrier services. Accident reports were limited to final reports meaning the accident investigation had been completed before the day of data retrieval and analysis of this study.

Coding Data

Data coding is a systematic procedure for synthesizing the significant meanings of texts by references and comparisons across different records and coders (Maxwell, 1998; Miles & Huberman, 1994). For a qualitative study, coding data is always an indispensable and taken-for-granted process (Gough & Scott, 2000). Based on the aforementioned analytical highlights of data coding, this study coded accident reports based on eight (8) main components. They were: (a) name of air carrier, (b) date of accident, (c) aircraft type, (d) number of fatality, (e) number of injury (both serious and minor), (f) aircraft/property damage, (g) cause(-s) of accident, and (h) factor(-s) of accident cause(-s).

Reliability and Validity

This study used cross-reference skill of qualitative data coding (QDA) double-checking the reliability from two codebooks obtained from different analytical time (August 10th and October 1st). The obtained reliability rate was 90.9% (ten out of eleven causes were concurred). In addition to the found reliability rate, the cause of "Weather" was collectively updated and combined into "Turbulence." About validity, the governmental information databases help researchers secure data validity pertaining to a qualitative research (Creswell, 1998). With this in mind, the NTSB's reports could satisfy validity criteria of a qualitative research (Berg & Latin, 1994; Creswell, 1998; Lincoln & Cuba, 1985).

Findings

The time-period of data retrieval and analysis was between June 18th and December 11th, 2004. There were total 189 final accident reports available on the NTSB's Docket System dated between January 1st, 1999 and May 31st, 2004. The finding sections were addressed as follows: 1) The causes of airline accidents, 2) The contributing factors of accident causes, 3) FTA model and probability simulation, and 4) Case studies and FTA reports.

The Direct Causes of Airline Accidents

The direct causes leading to FAR Part 121 airline accidents between January 1999 and May 2004 were ranked and categorized as follows (See Table 1):

Table 1
The Direct Causes of FAR Part 121 Airline Accidents

Rank	Accident Cause*	Number of Cases	% of Cases
1	Flight Operations	46	24.34%
2	Ground Crew	43	22.75%
3	Turbulence	40	21.16%
4	Maintenance	25	13.23%
5	Foreign Object Damage (FOD)	15	7.99%
6	Flight Attendant	8	4.23%
7	Air Traffic Control (ATC)	4	2.12%
8	Manufacturer	4	2.12%
9	Passenger	3	1.59%
10	FAA	1	0.53%

* See Appendix A for the definition of each accident cause

The accident cause due to Flight Operation error resulted in 46 accidents (24.34%), which was the most critical individual cause of the Part 121 accidents. There were 43 accidents as a result of Ground Crew error followed by Turbulence (40 cases), Maintenance (25 cases), FOD (15 cases), Flight Attendant (8 cases), ATC (4 cases), Manufacturer (4 cases), Passenger (3 cases), and the FAA (1 case). Although Flight Operations error was the most significant cause (24.34%), the dyad of Ground Crew and Maintenance (non-flight) error had resulted in 68 accidents (35.98% of the overall mishaps) as to 24.24% associate with Flight Operation error.

The Contributing Factors of Accident Causes

The factors leading to Flight Operation error were: 1) loss situation awareness, 2) misjudgment (ground clearance), 3) weather (contaminated, snowy, or icy runway), 4) ineffective communication, 5) operational deficiency (supervision, misjudgment, preflight inspection), or lack of training (heavy landing, go-around procedure, unfamiliar with regulations, and decision-making), 6) non-compliance with standard operational procedures (SOPs), 7) over-reaction (evasive maneuvers, abrupt reaction to Traffic Collision Avoid System (TCAS) warning), 8) physical fatigue, 9) weather and airport information ignorance (weather briefing, turbulence report, Notice to Airmen [NOTAM], Minimum Equipment List (MEL), outdated Runway Visual Range [RVR]).

The factors leading to Ground Crew error were: 1) poor situational awareness (clearance, airstair/jet bridge/vehicle operations), 2) ineffective communication (tug/truck/beltloader driver-pilots-wing walkers), 3) lack of supervision/quality assurance, 4) ramp agents' ignorance of safety criteria, 5) physical fatigue, and 6) personal health and medication.

Most accidents due to Turbulence resulted in flight attendant injuries. The factors that led to injuries or fatalities resulting in the cause of Turbulence were: 1) lack of weather awareness (pilots or dispatchers' poor discipline pertaining to weather evaluation), 2) inadequate training of cabin crews when encountering turbulence (inaccurate cabin reaction procedures, ineffective crew communication, delayed public announcement), and 3) passengers' inability of cooperating with cabin crews during emergency situation.

The factors that led to Maintenance error (equipment contamination, corrosion, engine failure, etc.) were: 1) the lack of quality assurance and supervision on performance, 2) non-compliance of standard maintenance procedures (SMPs), 3) FAA's incorrect data, 4) lack of training and knowledge, 5) rushed service, and 6) operational ignorance.

The factors that led to FOD cases were: bird/geese strikes and collision with deer. The FOD frequently occurred during: 1) take-off and lading phase, and 2) night flights around remote non-hub airports. Furthermore, the factors leading to the cause of Flight Attendant's mistakes were: 1) unfamiliarity with safety procedures during evacuation, 2) poor communication (between pilot, flight attendants, or ramp/gate agents), and 3) inadequate training with abnormal emergency conditions. In addition, the factors that led to the cause of ATC error were: 1) improper ATC service (the result was pilot's abrupt maneuver) and 2) a failure to provide adequate in-flight separation.

The factors contributing Manufacturers' error were: 1) inadequate manual information (e.g., gearbox maintenance manual), and 2) improper material and imperfect design. The factors that led to the cause of Passengers and their injuries were: 1) passengers' non-compliance with regulations during emergency situation, and 2) unruly passengers and behaviors. And finally, one factor leading to the cause of FAA was the FAA's improper issuance of airworthiness certificate and Airworthiness Directives (Ads) for specific parts.

FTA Model and Probability Simulation

The findings revealed that there were ten (10) main causes, along with 36 associated root factors, which led to airline accidents. A mini-FTA block diagram showed in Appendix B presented an inductive relationship among accidents (top-event), accident causes (second level events) and their root factors (the lowest level events) (See Appendix B). Each accident cause contained from one (1) to nine (9) contributory root factor(-s). Based on the Boolean logic symbols, "AND" and "OR" gates, researchers are able to examine the whole system from the bottom-up. These root factors (the lowest level events) included inadequate flight performance, fatigue, poor quality assurance, carelessness, air-rage, lack of situation awareness, non-compliance of SOPs, miscommunication, etc. The mini-FTA model in Appendix B also indicated that an individual root factor could create a category of accident cause (second level event) that eventually led to an accident (top-event) such as the "FAA."

To address the criticality of the 36 discovered root factors that led to the accidents, simulating accident probability of the top-event would help explain the significance of FTA model and predict the likelihood of the top event, an accident. For instance, based on Bowen and Lu's assessment of major airlines' safety performance in 2001 and 2004, the calculated probability of pilot fatigue (a root factor) leading to an accident was about $1.7\text{x}10^{-5}$ (1.7 cases per one hundred thousand flights) (Bowen and Lu, 2004). Because there could be hundreds of different factors associated with one accident cause, the probability for an accident cause to exist would be $(1.7\text{x}10^{-5})$ x 100, which is $1.7\text{x}10^{-3}$ (See Appendix C). Now, if any of the ten accident causes (an "OR" gate logic in this study) could lead to the top-event, the probability for an accident to occur would be $(1.7\text{x}10^{-3})$ x 10, which is $1.7\text{x}10^{-2}$ meaning 1.7 accidents for every 100 flights. This significant probability of accident should have drawn an attention of the aviation community.

Reversely, based on the same FTA model in Appendix C, if airlines can reduce the accident probability of each root factor to $1.7\text{x}10^{-7}$ instead of $1.7\text{x}10^{-5}$ (as a result of imposing safety trainings, new guidelines, flight training, or better navigation technologies), the ultimate accident probability of the top-event becomes $1.7\text{x}10^{-4}$ meaning 1.7 mishaps for every ten thousand flights. This simulation of accident probability shows that it is extremely critical for the airlines to mitigate potential hazards from the bottom-up as early as possible. If the probability of each root factor (the lowest level of the fault tree) could be compressed or even eliminated, the probability of accident causes (the second level of the fault tree) resulted from a combination of various root factors would be dramatically reduced. Eventually, the probability for the top-event/an accident to occur could be minimized.

Case Studies and FTA Reports

The main purpose of conducting FTA in aviation safety is to identify potential hazards, provide recommendations and reports, and prevent similar accidents happen again. In order to further strengthen the applicability of FTA accident model, case studies were provided.

Case 1. NTSB ID: NYC02LA013

Synopsis – "The captain briefed a "no go-around" for a night visual approach [to an airport]. The approach was not stabilized, and the airspeed decreased to the point of a stall. The airplane struck the runway in a nose high pitch attitude, on the aft fuselage, and settled on the landing gear. The first officer made initial callouts of slow airspeed and then stopped when the captain failed to respond to her callouts … [during interview] the captain reported that she briefed "no go-around" because no takeoffs were authorized on the runway at night … however, the first officer knew this was incorrect, but did not challenge the captain … Both pilots were described to having good flying skills. The captain said the first officer was passive and quiet. The first officer reported the captain was defensive and did not take criticism very well."

Cause and root factors – the captain's failure to maintain airspeed resulting in stall and hard landing. Factors involved were the failure of both pilots to comply with company's CRM guidelines, flight manual procedures, and the captain's improper approach briefing.

Training focus and comments – 1) recurrent CRM training, 2) pilot's flight procedure retraining, and 3) flight operation proficiency.

Guideline – AC-120-51D, Preflight SOPs, and airline's simulator training guidelines.

Case 2. NTSB ID: NYC03FA039

Synopsis: "The Boeing 757 was parked at the gate with passengers aboard when an Airbus that was being taxied struck the Boeing. The Airbus was being taxied to a gate by maintenance technicians. The taxiing mechanic reported that he activated the parking brake and waited for ground personnel and a jet way operator to arrive. After the ground personnel arrived he released the parking brake. The airplane did not move and he advanced the throttles out of their idle detent position … He pulled the throttles back and applied brakes; however, the airplane did not slow and continued until it struck the jet way."

Cause and root factors – aircraft technician's lack of training regarding aircraft system, maintenance procedures, and ground safety guidelines.

Training focus or comments – 1) imposing a recurrent training of maintenance standard operation procedures (SOPs), 2) aircraft system training, and 3) ground operation safety training.

Guideline – maintenance resource management (MRM) guidelines, AC-120-51D, manufacturer's system handbook or maintenance manual.

Case 3. NTSB ID: DCA03MA022

Synopsis – "… a Raytheon (Beechcraft) 1900D crashed shortly after takeoff from runway 18R at Charlotte-Douglas International Airport due to the airplane's loss of pitch control during take-off. The 2 flight crewmembers and 19 passengers aboard the airplane were killed, 1 person on the ground received minor injuries."

Cause and root factors – The lost of pitch control was resulted from an incorrect rigging of the elevator system compounded by the airplane's aft center of gravity, which was substantially out of limit. Contributing factors to the cause of incorrect rigging were: 1) lack of oversight at maintenance station from airline and the FAA; 2) improper maintenance procedures and documentation; 3) malfunctioning weight and balance calculation; 4) ineffective manufacturer's quality assurance onsite; and 5) the FAA's outdated weight assumptions.

Training focus or comments – 1) revising the FAA's weight-and-balance reference data, 2) imposing recurrent trainings for quality assurance (QA) inspectors both for airline and manufacturer, 3) providing aircraft technician's job compliance training, and 4) ensuring preflight SOPs.

Guideline – FAA rulemaking procedure and inspection handbook, maintenance trouble-shooting SOPs, preflight SOPs, maintenance resource management (MRM) guidelines, AC-120-51D.

Case 4. NTSB ID: DCA99MA060

Synopsis – "…a McDonnell Douglas DC-9-82 (MD-82), N215AA, crashed after it overran the end of runway 4R during landing … After departing the end of the runway, the airplane struck several tubes extending outward from the left edge of the instrument landing system (ILS) localizer array…The airplane was destroyed by impact forces and a postcrash fire."

Cause and root factors – "The flight crew's failure to discontinue the approach" and failure to ensure spoilers' extension for landing due to 1) flight crew's fatigue and stress, 2) situational awareness of airport weather, and 3) incorrect operation of using reverse thrust after landing.

Training focus and comments: 1) conducting recurrent CRM trainings for pilots, and 2) retraining pre and post landing procedures.

Guideline – AC-120-51D, flight ops SOPs.

Case 5. NTSB ID: LAX00LA223

Synopsis – "During takeoff, as the airplane accelerated through takeoff rotation speed (Vr), the outboard, forward cowl door on the left (number 1) engine separated from the engine nacelle and struck the horizontal stabilizer. The pilot reported there had been an abnormal vibration … An "RON-check" (Remain Over Night) had been performed during hours of darkness the previous night, which required that the cowling doors be opened. In the morning, the aircraft was handed over from the maintenance graveyard shift to the day shift. Maintenance items remained to be completed in areas of the aircraft other than the number 1 engine."

Cause and root factors – Mechanic's failure to refasten the cowling door prior to signing off the aircraft back to service.

Training focus and comments – 1) Retraining communication skills and quality assurance, and 2) Re-emphasizing team work capability.

Guideline – AC-120-51D, maintenance resource management (MRM) guidelines.

Conclusion

This study had discovered the ten (10) direct causes leading to accidents and 36 root factors behind accident causes. By using Fault Tree Analysis (FTA), aviation safety practitioners can design a more efficient and effective safety training program aiming to detect and eliminate hazards upfront. This study is concluded as follow:

1. Implementing system safety is feasible—System safety techniques could be applied to enhance aviation safety by airlines. In this study, the ultimate goal of conducting system safety analysis using FTA is to prevent future accidents by identifying potential hazards and providing countermeasures and recommendations. Although many studies had been accomplished measuring the overall safety performance (Bowen & Lu, 2001 & 2004a; Dahl & Miller, 1996, July 24; Goetz, 1998; Stroller, 2001), they did not provide a good model for safety practitioners to promptly and effectively identify hazards/root factors. Without identifying specific root factors and accident causes leading to mishaps, the value of solely measuring safety performance could be restrained and the cost of an aimless safety training could be very expensive. In fact, system safety experts advocates four (4) fundamental levels of safety precedence regarding hazard ramification. They are reengineering, redundant system design, warning signals/devices, and safety training/education. And the most inexpensive safety precedence is safety training and education (Vincoli, 1993). In today's airline business suffering from financial constraint but simultaneously concerning the highest degree of operational safety, offering safety training and education could be the most-acceptable means to enhance safety.

2. Fault Tree Analysis (FTA) is useful in targeting accident causes and root factors—In addition to Flight Operation error and non-flight working discrepancies, Turbulence (21.16%), FOD (8%); and Flight Attendant error (4.23%) also played a crucial role. Although ATC, Manufacturer, and the FAA do not cause accidents in a significant manner, once it happens, injured people or victims' families may still file lawsuits against government employees if such an accident was a case of willful misconduct (Hamilton, 2001). Thus, it is important to understand mini-FTA analysis because it helps safety enthusiasts (government or airlines) to effectively and promptly isolate accident postulates and implement strategic safety prevention programs from the bottom-up. Based on the mini-FTA diagram, any of the root factors on the bottom level can form a "cut-set" (a chain-of-events that can result in an accident or a system failure) breaking down the entire system. Hence, compressing or eliminating the failure probability of root factors from the lowest level of the mini-FTA diagram should be regarded as the training priority.

3. Human Factor training is critical—Regardless of the accident cause of Turbulence and FODs, human error was the primary factor leading to airline accidents in this study. Thus Human Factor training is essential to promote aviation safety. Krause (1996) and Orlady and Orlady (1999) stated that Human Factor is a very powerful training for pursuing an error-free and safety-laden airline operation. Human Factor training has delivered massive benefits to flight safety and surely to the flying public. Since 1990, the FAA has regulated CRM training, stemmed from Human Factor concept for flight crews, in Federal Aviation Regulation (FAR) Part 121 Subpart N for major air carriers and for Part 135 regional

commuters under SFAR 71 (Aviation Supplies & Academics [ASA], 2001), which was a great approach from the government.

4. Non-flight activities are equally hazardous—According to the findings of this study, lacking Human Factor training or an adequate ground safety education for non-flight workers (i.e. maintenance technicians and ramp agents) is questionable. It is simply because non-flight error constituted more mishaps (68 cases) than flight operation (46 cases). In fact, the aviation safety net consists of flight crews, maintenance personnel, air traffic controllers, airplane dispatchers, flight attendants, ramp agents, airport security, and all related professionals. Aviation practitioners should work closely together because a single flawed portion of the safety net could result in an unrecoverable safety breakdown and, thereby, human injuries, fatalities, or substantial financial loss. By the virtue of the "Swiss-cheese" safety model, aviation accidents could happen when possible unsafe acts or operators are present and line up simultaneously (Reason, 1990; Wood, 1997). With this in mind, in order to strengthen aviation safety net as a whole basing on mini-FTA model, it is reasonable for the aviation community to support a more proactive rulemaking process pertaining to a mandatory Human Factor or Maintenance Resource Management (MRM) training for ground and maintenance personnel.

Although the potential cost is always a big concern regarding an accident prevention program (Del Valle, 1997; Duke, 1999; Finder, 1999; Hahn, 1997; Morris, 2001; Morris, Rigavan, Whitelaw, Glasser, Strobel, & Eltahawy, 1999; Ott, 1997; Wald, 2000), providing safety trainings to employees would consume the least amount of financial sources. According to system safety guidelines, the prevailing methods of implementing an accident prevention program include system re-engineering, administrative reform, and work practice controls (Brown, 1976; Gloss & Wardle, 1984). If system re-engineering and administrative reform are too costly to adopt, work practice control (a.k.a. safety training) is the most cost-effect method to prevent potential accidents. Yet the safety training should be a mandatory or routine one. Otherwise the effectiveness of training would be lower-than-expected (Lu, 2003; Bowen & Lu, 2004b; Vincoli, 1993).

The doctrine of system safety is very useful in accident prevention and safety enhancement. Aviation safety enthusiasts could utilize system safety techniques like FTA model and reports to identify potential hazards associated with airline operation and recommend needed safety trainings for their employees. Despite the immediate goal for the aviation industry to regain its revenue after 9/11 attacks, maintaining a risk-free aviation environment should be positioned as the top priority for airlines and our government. Aviation accidents are still a threat to the flying public because accidents occur periodically and will claim lives again. From the public's standpoint, each accident will become a metaphor of either the government's or the airline's failure to adequately protect its "clients." The flying public needs a true Safer Skies and using system safety in this study has demonstrated a new approach to accomplish the goal of zero accidents.

Future Study and Comments

In order to reduce the cases of aircraft accidents resulting from Turbulence and bird hazard/Foreign Object Damage (FOD), the aviation community needs to put more efforts on meteorological, technological, and biological studies.

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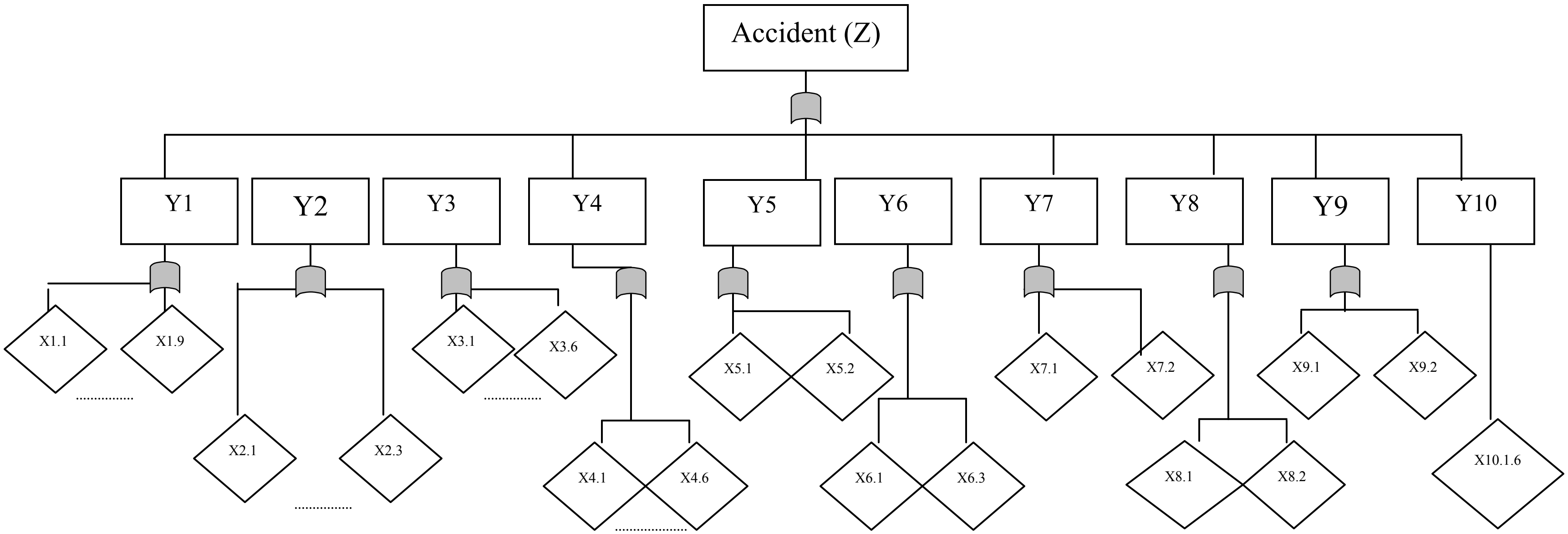
Appendix A
Terminology of Accident Causes

In this study, the causes leading to an accident were categorized and defined as the following for a better understanding of research findings:

- Flight operation: an accident was caused by cockpit crews
- Turbulence: an accident was caused by turbulence (in-flight, clear air, wake turbulence)
- Maintenance: an accident was caused by aircraft maintenance personnel
- Ground crew: an accident was caused by ground crews (truck driver, beltloader or tug operator, ramp agents, etc.)
- Foreign object damage (FOD): an accident was caused by birds, animals, and any objects that do not belong to aircraft itself
- Flight attendant: an accident was caused by flight attendant's inadequate emergency actions
- Air Traffic Control (ATC): an accident was caused by air traffic controller's misjudgment
- Manufacturer: an accident was due to manufacturer's design, official inspection manuals, etc.
- Passenger: an accident was caused by passengers themselves
- FAA: an accident was caused by FAA's discretionary function regarding certificate approval, inspection, etc.
- Non-flight error: a combination of maintenance and ground crew's operational mistakes.

Appendix B
Fault Tree Analysis (FTA)



Note: Y1: Flight operation; Y2: Turbulence; Y3: Maintenance; Y4: Ground crew; Y5: FODs; Y6: Flight Attendant; Y7: ATC; Y8: Manufacturer; Y9: Passenger; Y10: FAA; X1.1: situation awareness; X1.2: misjudgment; X1.3: weather; X1.4: communication; X1.5: operational deficiency; X1.6: SOPs, X1.7: over-reaction; X1.8: physical fatigue, X1.9: weather ignorance; X2.1: weather awareness; X2.2: inadequate training; X2.3: passengers' non-compliance; X3.1: QA; X3.2: SMPs; X3.3: FAA's incorrect data, X3.4: training; X3.5: rushing service; and X3.6: ignorance; X4.1: awareness; X4.2: communication; X4.3: QA; X4.4: ignorance, X4.5: fatigue, X4.6: health and medication; X.5.1: birds; X5.2: deer; X6.1: evacuation; X6.2: communication; X6.3: training; X7.1: ATC service; X.7 2: flight separation; X8.1: manual; X8.2: design; X9.1: non-compliance; X9.2: late respond; X10.1: airworthiness certificate and Airworthiness Directives (ADs); Domino effect: X → Y → Z;  is a logic symbol of "OR" gate in system safety program.

Appendix C

Simulating Fault Tree Analysis and the Probability of the Top-Event