Commercial Aviation Safety and Risk

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Airline safety research affects policy recommendations, so the scale of a safety index creates important effects. Indices of safety and airline financial health, safety and airline size, safety and government oversight, and the public perception of safety are surveyed. Conclusions depend on data selection and statistical techniques. Aircraft accidents are infrequent and random, making any testing difficult. Overall, time progression and a rough airline size-safety relation, with important qualifiers, are correlated with safety. The literature survey raises recurrent questions that are analyzed further in statistical testing of recent aviation accidents. National Transportation Safety Board accident investigations report data for 1966 to 1990. Statistical tests measure the effects of deregulation, technological progress, Congress, and FAA in accident prevention. Deregulation and FAA have had positive effects on airline safety above and beyond technological and time improvements, though FAA faces diminishing returns.

Measurement of airline safety provokes controversy because safety levels affect federal approval of airline mergers; alter federal funding of air traffic control, airport repairs, and aircraft safety studies; and could prompt policy makers to roll back or expand airline deregulation. "Safety" itself is not some constant index like temperature, but may be measured in accidents, minor mishaps, or fatalities, against miles traveled, against number of flights, or over time. Airline safety can compare ground travel, short flights, commuter flights, or international flights. Different methods of measuring safety may contradict each other, adding to the puzzle of how to improve safety when it is difficult to even ascertain what is safer.

For example, if safety is measured by accidents over distance flown, then an airline that makes numerous short flights and crashes very infrequently may have the same safety record as an airline that flies only from Japan to San Francisco and crashes every other trip. However, the average traveler is probably much more willing to take a series of 50-mile hops on the short-distance airline than to take the flight to Osaka. If the same airlines are compared by accidents per departure, the Pacific flight is more dangerous, yet the statistic hides the fact that the longer flight spends more time in the air and faces more time without emergency airport assistance in which to crash.

Measures of safety and several such measurement problems are surveyed, and the accident record of United States commercial airlines is statistically analyzed. The survey reveals strengths and weaknesses of current safety analyses.

The view of a United States air traveler is adopted, so the focus is on transport used by most United States travelers: larger U.S. airline companies—or Part 121 air carriers in FAA parlance—flying to and from U.S. and territorial scheduled destinations. Commuter airlines are included where commuters operate as a substitute for large jet transport (for example, code sharing).

The safety record of the airline industry has improved continuously, so that accidents have become rarer (three occurred out of 7 million departures in 1990). Safety improvements by manufacturers, airlines, employees, and government oversight agencies ensure that fewer and fewer accident trends even show up. Accidents must be assumed to be random, or at least independent events, the products of a confluence of several random safety threats such as bad weather, improper navigation, engine trouble, and poor judgment.

Researchers have looked for systematic influences on the random output, accidents, from several areas. These inputs can be divided into four groups: the financial-safety relation, the size-safety relation, the political structure-safety relation, and public awareness of airline safety. Financial theses usually propose that airline deregulation engendered cutthroat competition, which has caused airline firms to cut back on maintenance, causing accidents. The size-safety thesis postulates that airline size is related to maintenance expenditures, which affect safety. The political-structure-and-safety relation examines the market's ability to ensure safety and whether travelers choose the airlines that best meet their air safety wants. Finally, public-perception research asks whether the public competently measures safety and whether safety indices matter.

FINANCIALS AND "MARGIN OF SAFETY"

The theory of the "margin of safety" states that regulation held up airline fares to increase airline profits and, in addition, allowed airlines to spend more on inputs. During regulation, airlines could afford to exceed the FAA-mandated minimum level of safety inputs, regulated by maintenance and inspection. The margin was a cushion above the hard minimum. Deregulation exposed airlines to price and cost competition, which has caused them to reduce pay scales, increase employee work hours, shrink seat width, and shrink the safety margin. The shrinkage made airlines, according to Nance (*1*), "obviously . . . by definition, less safe." However, "this decline has nevertheless failed to show up as a measurable increase in accidents and/or casualties."

The margin of safety theory will not hold if FAA is not the dictator of minimum safety levels (i.e., if airlines supply safety to suit travelers' desires). Chalk (*2*) examined whether FAA really ensured a minimum safety level through its inspection and fine system. The average fine of $1,000 for a safety violation was a mosquito bite on the financial sheet of the major

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airlines. Chalk found that rule interpretation was capricious and inconstant. Safety enforcement varied in definition, time, and place. Chalk concluded that FAA enforcement did not determine airline minimum safety.

Golbe (*3*) examined statistically the relation between operating margins and accidents per departure, testing whether wider margins correlated with fewer accidents. Using a sample of 11 large airlines from 1963 through 1970, Golbe found that firms with higher profits also had higher accident rates. The speculative answer to these results is that larger firms had both high profits and more flights, and with more flights went more accidents.

Golbe identified a few measurement problems, including the fact that use of accidents per passenger mile as a measure of risk discriminated against airlines that typically fly short trips. Golbe asserted that 70 percent of accidents occur during takeoff or landing, as opposed to en route flight, and used an accidents-per-departure measure as a cure. However, 70 percent implies that her risk measure may be only 70 percent correct. Furthermore, if the analysis were extended to the deregulation era, the error would be worse. Deregulation decreased the number of stops per flight; therefore, use of accidents per departure would make the deregulation era look less safe.

Golbe also noted that fatalities, her risk variable, would make full planes look more dangerous. An airline company filling all its planes, and doing better financially for it, would have a greater number of fatalities per accident than if a plane only half full had crashed. More passengers per plane, or higher load factors, are also a characteristic of deregulation.

Finally, there is more than one way to measure profit. Golbe used net income over the gross national product (GNP) deflator to represent not only better maintenance, an expense, but also purchase of new planes, a capital improvement. She included GNP to signify periods of greater demand and congestion, but it did not affect accident rates.

Despite Golbe's finding that higher accident rates go with higher margins, Rose (*4*) found that profits have an influence on safety, once all other factors are controlled. Accidents occur so infrequently that there is a lot of "noise" in estimating their causes, so Rose removed certain influences from the estimation. Once the primary accident-correlated conditions of flight length, number of takeoffs and landings, and international and territorial flights were taken out, Rose found that operating margins also affected accidents, for small airlines. Operating margins on large airlines had no effect.

Rose avoided the per-mile and per-departure debate by measuring accidents per year for each airline; this actually opens her work to criticism from both fields. Data from 35 airlines for 29 years (1957 to 1986) were used; still the data were difficult to work with because of the small number of accidents. An interesting side point can be made about Rose's method of testing: because of the noisiness of the data, a Poisson distribution was used, and grouping in the errors was corrected by taking the square root of the independent variable. This technique, though widely used in aviation studies (*4–6*), has no strong theoretical justification.

Theoretically and statistically, the financial-safety thesis is weak, if not a failure. An explanation for the failure raises a new thesis: larger airlines may tend to have better managers, steadier profits, and possibly better safety rates.

SIZE AND SAFETY

Larger airlines can offer better salaries, more power to executives, a better-stocked repair shop, and larger planes that are easier to repair and fly. Larger airlines may be safer. The 20 largest commuter airlines are twice as safe as the next 30 largest commuters and carry more than half of all commuter passengers, according to Oster and Strong (*7*). The 20 largest are six times safer than all the smaller air travel companies, measured by the joint probability of being involved in a fatal accident and being killed in that accident. Nearly all of the 50 largest commuter airlines share computer reservation codes with a major airline.

Oster and Strong claim that there is a perverse "safety mismatch" in the size-safety relationship. A self-trained pilot may get his first job flying for a small commuter; he has the least experience, flying the smallest, hardest-to-maintain planes, on poorly kept airfields, with the greatest lack of instrument support. Large airline pilots, on the other hand, with 20 to 30 years of experience, fly the safest aircraft, from well-maintained airports, with complete weather and air traffic support (*8*). It would be a wonder if major airlines did not have lower accident rates than the smaller companies.

Accordingly, Golaszewski and Bomberger (*9*) found that whereas accident rates vary with the size of airlines, the difference is most pronounced among the smallest airlines. Among the major airlines, no one airline had a different safety rate. The majors, which are the common means of transport for most travelers, as a group had a better safety rate than smaller planes. The majors' safety rate is particularly difficult to measure because of the rarity of accidents.

Airline size is defined by flight hours or number of departures. The choice of the size variable affects the results. Differences in safety rates are more pronounced when accidents are analyzed per flight hour and hardly significant when analyzed per departure. Rose (*4*) found that the safety-by-departures rate has less variance than other safety measures.

Because of repeated difficulty with insufficient numbers of accidents to perform statistical testing, researchers have tried to find other measures of safety. Maintenance expenditures make a poor measure, since they vary with company size and type of plane. Further, as Rose (*10*) pointed out, companies use maintenance dollars with varying effectiveness. And $100 of maintenance expense cannot be considered equal to $100 of new aircraft, though both are safety inputs.

The National Transportation Safety Board (NTSB) records both accidents and incidents. An incident is a small abnormality in aviation operation, such as brake slippage, improper repair procedure, or flying at an incorrect altitude. Incidents indicate that some part of the overlapping system of safety features in an aircraft or airport is not performing up to full potential. Incidents are more frequent than accidents, but incidents perform poorly as safety measures.

Golaszewski (*11*) tested the size-safety relation using accidents, incidents, and enforcements alternatively as safety indices. Enforcement refers to the yearly fines FAA levies against airlines for safety violations. The incident rate and the enforcement rate were not consistent with the accident rate: airlines that appeared most risky according to one scale were moderate or even most safe on the other two scales. The lack of correlation may occur because incidents are voluntarily reported and subject to "enthusiasm" bias. The Newark and West Virginia airports report far more incidents than other areas; this is probably due more to enthusiasm than actual risk (*12*). Enforcements are suspected to be similarly more sensitive to the mood of FAA than to actual risk (*8,13*).

Two other possible measures of safety remain: one is near-midair collisions, a subclass of incidents, which occur when two aircraft pass within as much as 2 mi of each other. Closer encounters are highly publicized. The federal government created the other possible measure when it conducted the 1984 National Air Transportation Inspection (NATI) program, which assigned safety ratings to several airlines on the basis of a rigorous inspection. Kanafani and Keeler (*6*) examined maintenance expenditures, NATI ratings, and near-collisions of each airline, and found that maintenance significantly explained safety of new airlines, while NATI and near-collisions did not.

The Kanafani and Keeler examination of new airlines is valuable because it addresses size, finance, and free-market incentives (political structure) all at once. Airlines that started service since 1978 are smaller, have small profit margins, and may be more responsive to travelers' safety wants because they do not yet have a reputation for safety. This study found that new airlines spend more on maintenance and have better safety records. Many new entrants had no accidents during their entire service careers.

In possibly another example of "market enforcement," Rose (*10*) found that, even near bankruptcy, airlines do not skimp on safety. Near bankruptcy a firm's president is thinking of the company's resale, especially planes. The value of a company is enhanced by a safe record and proper maintenance.

Larger airlines have more accidents simply because they handle more traffic and have greater exposure to risk. By another measure, the major airline companies and their code-sharing partners are far safer than smaller airlines. Among the major airlines themselves, size appears to make no difference. It is safe to conclude what technological research has already shown: larger companies tend to have larger, safer planes and attract successful pilots through better wages and job security. Very roughly, bigger can be better.

POLITICAL STRUCTURE: THE "MARKET AS ENFORCER" THEORY

In the face of uncertain results of financial-safety and size-safety studies, another rough correlation appears: whereas the largest airlines tend to be safest, they also tend to be located in the western world. Airlines not sheltered by national ownership or national monopoly must provide the safety level demanded by finicky travelers, who can choose among airlines. Oster and Strong (*7*) test this idea in a way that takes unique advantage of a measurement problem. One approach toward accident causality is that the first mishap created the opportunity for danger and thus caused a subsequent crash. A second approach is that the accident could have been avoided up until the last possible contributing factor. Oster and Strong reason that if free markets force airlines to cut costs, under deregulation, maintenance and equipment should show up as a first cause more often. Cost-cutting pressure on the crew should cause pilot error to show up more often as the final cause. Even if total accidents do not increase, under deregulation these causal trends should appear.

The results confirm the opposite. Equipment-related accidents in the deregulated period are less than one-third of those in the regulated period in the United States. Cockpit crews, now facing more diverse tasks, have become more effective. The reason for the latter result may be that, before deregulation, many pilots held second jobs and consequently did not use the time alloted for rest (*14*). There has also been growing emphasis on cockpit training.

The number of new, younger pilots in the airline fleet is frequently mentioned as a source of air travel risk. Lauber (*15*) reported that the median experience level of pilots involved in accidents had fallen from 16,000 hr (1975 to 1978) to 13,000 hr (1982 to 1985). However, the entire fleet of airline pilots is on the average younger, and any subsample, whether the ones that are involved in accidents or the ones that eat fish, is also younger. The important question is whether youth or inexperience has caused more accidents, and neither has been proven. In fact, aircraft accident reports reveal that in the 1960s and 1970s many older pilots had heart attacks in the pilot seat, and some even died.

Oster and Strong (*7*) also hypothesize that increased air travel since deregulation caused more aircraft to crowd the sky, creating more air traffic control errors. Again, their results do not support the hypothesis. Oster and Strong may be victims of a measurement problem or a misperception. The measurement problem is that control errors are recorded as incidents unless a crash results. However, pilot errors are recorded as accidents, though the air traffic error and the pilot error pose equal risk (*4*). The misperception is that the skies are more crowded. In the face of the 1981 Professional Air Traffic Controllers Organization strike, FAA cut air traffic to 75 percent and capacity of 23 major airports to 50 percent of prestrike levels. FAA also eliminated in-air holding, literally clearing the skies. Congestion contributed to more accidents in 1961 than any year since.

Certainly the air traffic controller strike was important to the deregulatory era. Before the strike, 17,275 worked in air control. As a result of the strike, 11,400 were fired (*16*). Deregulation dramatically increased air travel; there were 26 percent more departures in 1985 than in 1981, and the number of air controllers was still 15 percent less than before the strike (*14*).

Deregulation's influence on air traffic control and on safety is obscure. Congestion, increased staffing, and airspace complexity covary as much as 81 to 91 percent, according to Gifford and Sinha (*17*). In traffic control airspace surrounding large airports, they found staffing levels positively associated with near collisions, possibly because complicated airspaces get more staff, and the complexity still causes near-collision errors.

Oster and Strong (*7*) found the cost-cutting theory reversed, and instead airlines performed more safely after deregulation. In the case of air traffic control, improvement is due to FAA involvement: deregulation may mark less governing and better guidance.

RANDOMNESS

Deregulation had a positive effect on safety, but safety causality still defies identification. Even the improvement of deregulation is difficult to identify because of continual technological progress and self-improvement of the industry. Research and innovation in cabin design, metallurgy, fuels, floor lighting, evacuation slides, and airport weapon detection improved safety dramatically in the last 30 years. According to NTSB, 65 percent of crashes are survivable, and the chance of surviving "survivable" crashes grows over time. However, these changes create a trend in safety improvement that obscures the effects of deregulation.

Barnett and Higgins (*5*) assumed that accidents were random, then tried to separate deregulation and technology. They concluded that air travel is 60 percent less safe because of deregulation. They assume that new airlines since 1978 are dangerous, and the traffic they attract away from older airlines is therefore risky; therefore the aggregate safety level is 60 percent lower than what it could have been. The derivation of the 60 percent is ambiguous. Their conclusion conflicts with Kanafani and Keeler's statistical analysis of new airlines (*6*).

Barnett and Higgins created a useful safety statistic, X/N, where X is the death risk per flight and N is the chance of being involved in an accident on a particular departure. Two important components of risk are encompassed, though it is still vulnerable to departure-based criticism. They apply their measure to international safety levels and find that United States carriers are the safest in the world.

Political structure is difficult to test without comparing, and deregulation's results on safety are ambiguous. Barnett and Higgins name the ill effects of deregulation, but their proofs are logically incomplete. However, the importance of deregulation as a move toward freer markets and traveler-demanded safety levels will be canceled if travelers are not aware of safety levels.

PUBLIC AWARENESS

Public awareness may depend on who pays for accident losses. Panzar and Savage (*18*) find that if liability rules are structured so that the airline pays for losses from a crash, the airline firm will insure against crashes. Theoretically, insurance will cushion the financial impact of the crash, lessening the incentive to improve safety, a phenomenon called moral hazard. If the traveler bears the loss of the crash (caveat emptor), then the traveler will purchase flight insurance and invest in safety information. If insurance companies have limited information about safety, they will offer only one insurance policy, which means that either the patrons of safe airlines will pay too much for insurance, or travelers will refuse to fly riskier airlines. This asymmetrical information is known as adverse selection.

Either way, travelers will only pay as much as they desire to be as safe as they think reasonable. An imaginary result of this scheme would be grades of airlines: some "mostly safe," others "more safe," and so on. "More safe" airlines would cost more, only fly on sunny days, employ only perfectly seasoned pilots, and prohibit carry-on luggage.

Panzar and Savage claim that regulation forced aviation to be safer than people desired (optimum), and after deregulation, market forces pushed safety down toward its optimum, lower, level. However, the point could just as easily be made that travelers desired more safety, but regulation emasculated their desires by ensuring profits regardless of "mostly safe" and "more safe" selection. Panzar and Savage reach their conclusion by noting that fares are, on the average, lower after deregulation, and it cannot be that travelers are paying less to get more.

However, once the market is freed, a small, mobile, and aware group of consumers may be enough to create market discipline of airlines, according to Moore (*14*).

The public may in fact be hypersensitive to airline risk as opposed to other equal risks. Barnett and Higgins (*5*) suggest that the frequency of incidents creates the perception of extra risk.

Borenstein and Zimmerman (*19*) tested the traveler response to safety indicators in terms of falling demand for airline stock ownership and air travel. Accidents indicated safety levels, and dips in share price after an accident indicated public awareness, or stockholder predictions of travelers' upcoming decisions. Air travel demand is difficult to measure, since price, frequency of flight, time of year, and fullness of planes must all be reckoned. For example, after the Air Florida crashes, Air Florida's planes were fuller, which would indicate higher demand, but could indicate lower frequency of flights. Borenstein and Zimmerman approximated demand from leftovers in a statistical test: everything not already explained by the variables included was assumed to be demand. This method, though common in statistical testing, is not very reliable.

Nevertheless, their results have been widely cited, especially the 3-month period of lower stock prices after a crash, though this result was not statistically significant. Borenstein and Zimmerman attribute this lack of significance to the disincentives of insurance coverage; both travelers and airlines are cushioned from poor safety vigilance. The lack of statistical significance and imperfection in estimated demand are flaws in this widely recognized study.

The chance of being involved in a near collision is extremely small, but the public appears terrified of that tiny possibility. Consider the news media treatment: "Our Troubled Skies," *Time*, Aug. 10, 1987; "Worries in the Busy Skies," *U.S. News and World Report*, Aug. 24, 1987; "Year of the Near-Miss," *Newsweek*, July 27, 1987; "Wrong Track (Near Misses and Sloppy Safety)," *Time*, Sept. 14, 1987; "Dangers in a Crowded Sky," *Macleans*, Aug. 31, 1987; and "The Gremlins in the Sky (Near Misses)," *U.S. News and World Report*, July 20, 1987. Golaszewski (*11*) studied individuals' evaluations of risk from different sources and concluded that the public is overly frightened, relative to actual risk, of airline crashes because of their catastrophic nature.

Golaszewski noted that the chance of being involved in a near-midair collision is extremely rare. A frequent flyer would have to fly 120 flights a year for 250,000 years to equal the probability of being involved in one with certainty. Yet pilots and public are aware and concerned about their presence.

Hypersensitivity appears to have been the result when an engine fell off a DC-10 over Chicago in 1979, according to Lefer (*13*). The last time equipment failure caused an accident was 1973, 6 years and several million flights ago. According to the Air Transport Association (*20*), there had been 521 accidents from 1959 through 1978, and 71 of the 521 involved fatalities. Ten of the 71 were due to equipment failure. FAA grounded the DC-10, one the industry's most popular planes, because, according to Lefer, "Congress was prompted to legislate . . . the FAA probably overreacted . . . but probably had no choice in the face of the media storm." The accident was later found to be caused by a time-saving maintenance procedure used by American Airlines.

A NEW SAFETY MEASURE

Commentators portray 1985 as one of the worst years for airline safety. An Aeromexico jet collided with a small aircraft above Los Angeles; FAA issued record fines; a military charter plane crashed in Newfoundland, killing all aboard. All the accidents were tragedies, yet most United States travelers do not fly on foreign airlines, military charter flights, or small private planes, or fly on them rarely. All of these are significantly more dangerous than the most common transport, United States scheduled airlines. A more germane safety measure for United States travelers must exclude foreign, charter, and military flights.

Similarly, airline passengers are not threatened by ground crew injuries, flight attendants' sprained ankles, or pilot indigestion, yet all these are included in the official accident statistics that most researchers use. A rigorous examination of direct danger to average United States passengers would be informative.

STATISTICAL ANALYSIS

Mishaps such as flight attendant injury, ground crew accident, or foreign or charter flight accidents do not indicate risk probability of United States airlines fatal accidents and should be measured on different scales. Inclusion of non-life-threatening mishaps as accidents in aggregate accident statistics is misleading. Inclusion of accidents generated by foreign safety systems, foreign pilot training, and incentives obscures the causes in the United States airline accidents. Most airline safety studies use these aggregate figures.

Aggregate accident statistics fail to discriminate between danger and potential danger. Aviation safety is made up of an overlapping system of safety nets. Though considered an accident, a single case of pilot incapacitation or engine fire is not enough to cause a crash; other factors must contribute. These incidents are poor safety indicators. Mishaps are informative if they illustrate accident causality, not just chance abnormalities.

For this analysis, accidents are defined as abnormal occurrences in which one or more passengers are seriously injured in a manner directly connected with operation of the aircraft, or instances involving collisions with the ground or other aircraft that signify real threat to the safety of passengers. This definition omits irregularities among crew or aircraft that are safely resolved yet are included in the official accident statistics.

To satisfy the preceding concerns, accident data were culled from NTSB accident reports, the source of the aggregate accident figures. Accident reporting terms also changed in 1978, 1981, 1982, and 1985 (*21*). By researching NTSB "accidents" from accident reports, years of comparable data are assembled, and equally serious accidents in 1985 and 1966 get the same classification, despite what the official reports choose to call them.

Data are derived from NTSB Annual Accident Reports, 1966 through 1990. Miles and departures are from FAA; 1989 and 1990 miles are estimated. Accident data exist from 1929, but because of continually changing reporting standards, data before 1966 could not be included for this study. To illustrate, in the early 1960s, before NTSB was formed, accidents were often attributed to "crashed while enroute."

Accidents, Departures, and Mileage

The data are used to examine first which measure is more accurate, accidents per departure or accidents per mile. It is hypothesized that if 70 percent of all accidents occur at takeoff or landing, departures will have a higher correlation with accidents than mileage.

Departures have significant explanatory power. Revenue passenger miles are negatively related and significant to annual accidents. Time (technology) trend is correlated both with departures and revenue passenger miles. Inclusion of technology lowers the significance of departures from 3.43 to 2.4 and the significance of miles from −5.1 to −1.2. Caution must be used with statistical interpretation: one reading of these results implies that longer flights are safer than shorter flights.

Tests of Accident Causes and Factors

The second investigation seeks to discover which factors influence accident risk. Risk is deflated by departures, following the preceding results, and tested against factors cited as causes in accidents, including congestion, air traffic control, and jet innovation. Deregulation and FAA activity are included to find out whether either has had an effect on safety.

FAA activity is measured by the number of airworthiness directives (ADs) issued annually. ADs are commonly issued after an airline accident. Many ADs come from the manufacturers of the aircraft, the engines, and various parts. Therefore, to the extent that they incorporate manufacturers' warnings, ADs are not a pure measure of FAA accident-prevention activity. However, those warnings reflect the liability environment surrounding air travel, which is under the purview of the federal government and influenced by FAA.

These results are reproduced in Table 1. In the test of total accidents, the R-square fit measure is .9998. The high fit number is not attributable to autocorrelation or abnormal errors common in airline accident data, since correcting for both did not change the coefficients or the R-square. Deregulation is significantly negative, indicating that deregulation is correlated with fewer accidents. The time (technology) trend is barely significant with the wrong sign. FAA ADs show significant risk mitigation but lose their effectiveness after a certain point, as expected. The 113th FAA AD achieves maximum safety; the rest are less useful.

Statistically, the error terms above may not be normally distributed because of the rarity of accidents. Consequently, the analysis is repeated using probit analysis to mitigate error abnormality. In this test, the positive or negative influences of factors mimic those of the fully specified equation above, though none of the influences are statistically significant. Perhaps accident rarity creates errors that covary with factors.

TABLE 1 RELATION OF RISK TO ACCIDENT FACTORS (EQUATIONS 1, 2, AND 3)

Equation 1: Risk = Accidents/ Departures; R-square = .9998
Equation 2: Probit of Equation 1; R-square = .5849
Equation 3: Fatals = Deaths/ Departures; Fatals R-square = .9276

Risk =	Time +	FAA AD +	Log (FAA) +	Pilot +	Mid Air Collis. +	Weather
Coef.	.713E-7	-.256E-7	.288E-5	.217E-6	-.554E-6	.142E-6
[Tstat]	[1.73]	[-3.55]	[3.89]	[4.05]	[-2.91]	[3.09]
Probit:	8.96	-1.38	154.47	16.03	-28.37	-3.35
	[.579E-5]	[-.551E-5]	[.585E-5]	[.52E-4]	[-.108E-4]	[-.868E-5]
Fatals:	-.143E-5	-----	-----	.395E-5	.492E-5	.305E-5
	[-.643]	-----	-----	[.79]	[.416]	[.677]

	+ Traffic Control	+ Congestion	+ Maint.	+ Aircraft	+ Other Pilot
Coef.	-.297E-6	.180E-8	.654E-6	.377E-6	.102E-6
[Tstat]	[-2.46]	[2.94]	[4.77]	[5.7]	[3.93]
Probit:	-35.62	85.11	14.01	21.58	60.96
	[-.124E-4]	[.717E-5]	[.566E-5]	[.263E-4]	[.914E-5]
Fatals:	.909E-5	-.631E-5	.298E-5	.794E-5	-.152E-4
	[.731]	[-.136]	[.265]	[1.72]	[-.878]

	+ Sabotage	+ Mechanical Fatigue.	+ CoPilot	+ Crew	+ Airport	+ Seatbelt
Coef.	.208E-6	-.366E-6	-.147E-5	-.135E-6	.595E-7	.585E-6
[Tstat]	[3.27]	[-10.17]	[-11.48]	[-5.83]	[3.37]	[9.75]
Probit:	7.07	-20.23	-102.49	-3.912	4.83	29.04
	[.633E-5]	[-.708E-5]	[-.183E-4]	[-.382E-5]	[.684E-5]	[.703E-5]
Fatals:	.746E-5	-.89E-5	-.215E-4	.831E-5	.491E-5	-.588E-5
	[1.51]	[-1.184]	[-.507]	[-1.639]	[.843]	[-.538]

	+ Alaska	+ Birds	+ Evacuation	+ Deregulation	+ Jet Innovation
Coef.	.193E-6	.143E-5	.181E-6	-.135E-5	-.146E-6
[Tstat]	[10.75]	[15.45]	[5.03]	[-10.33]	[-.528]
Probit:	1.807	74.82	10.28	-130.96	67.624
	[.171E-5]	[.232E-4]	[.893E-5]	[-.776E-5]	[.409E-5]
Fatals:	-.283E-5	.208E-5	-.467E-6	.147E-4	.191E-4
	[-.417]	[.0822]	[-.0666]	[.527]	[.2758]

It has been a puzzle whether the fuller planes after deregulation lead to more fatalities in a crash. Crashes are less frequent since 1978, yet each may have more fatalities because of higher load factors. Testing passenger fatalities per departure, or death rate, against accident factors indicates how deregulation affected the death rate. Seating before and after deregulation must be assumed to be random and have no effect on the death rate. The test indicates an insignificant relation between deregulation and the death rate: deregulation had no effect.

Because of the suspicion of abnormal errors in the test on accident causes, a second data set from more diverse sources was tested. Annual rainfall proxies for weather, annual passengers for congestion, aviation industry's hourly wage for maintenance cost, and airline profits are included. The results have their expected signs, and autocorrelation and abnormal error correction did not change the results (see Table 2). Time trend decreases risk, congestion increases it, and the introduction of jets reduced risk. Deregulation and FAA ADs are ambiguous. There appears to be a trade-off between time and deregulation. Depending on the specific equation used, one or the other is significant.

Congressional Activity and FAA Effectiveness

Observers have asserted that Congress passes laws and puts pressure on FAA to act in the wake of an accident. Ott (*22*) writes of "short-term, hastily prepared technology programs that Congress has required in wake of aviation accidents." Congressional concern is understandable. In testing this concern, accidents and hearings should be correlated. If FAA, in response, acts in a knee-jerk fashion, hearings and ADs should be correlated. However, FAA may be acting immediately after accidents to keep Congress off its back, and an AD would immediately follow every accident. The influence of FAA on safety and Congress on FAA is examined.

Eight years and 216 observations of congressional hearings, FAA AD activity, and accidents indicate little evidence of the relations expected. FAA issued ADs 2 weeks after an accident, and not significantly at any other time (lags of up to 16 weeks were tested). Hearings also follow 2 weeks after accidents, though in all cases, the *T*-stats are less than 1. Though the results are not significant, they imply that both Congress and FAA react simultaneously to accidents and do not pull each other's strings explicitly (see Table 3).

TABLE 2 RISK AND FACTORS REVISITED (EQUATION 4)

R-square = .8294

Risk =	Rainfall +	Time +	Transport wage +	Airline Profit +	# Passengers
Coef.	.738E-8	-.917E-6	.966E-6	-.111E-6	.196E-13
[Tstat]	[.0679]	[-1.53]	[.877]	[-.843]	[1.44]

	+ Deregulation	+ Jet Innov.	+ FAA ADs	+ log(FAA ADs)
Coef.	.457E-7	-.253E-5	-.128E-7	.211E-5
[Tstat]	[.0339]	[-1.85]	[-.436]	[.684]

TABLE 3 ACCIDENTS, FAA ACTIVITY, AND CONGRESSIONAL HEARINGS; ALSO, ACCIDENTS AND THE AIR TRAFFIC CONTROL STRIKE (EQUATIONS 5, 6, AND 7)

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Equations 5-6: Relation of Air Safety, FAA ADs and Congressional Hearings
R-square = .0518
(Figures are for two week periods; Accident-2 are accidents three and four
weeks ago, and FAA ADs+2 are ADs two weeks in the future.)

Hearings =  Accident + Accident-2 + Accident-4 + Accident-6 + Accident-8
Coef.         .1933      -.03378       -.0579       -.06301      -.0915
[Tstat]      [.7494]    [-.4061]      [-.7034]     [-.7655]     [-1.11]

           +Accident-10  + Time + FAA ADs+2  +  FAA ADs+4
            -.03228       -.0258   .002698       .03885
           [-.3875]      [-2.056] [.09898]      [1.4346]

R-square = .0695
FAA ADs = Accident  + Accident-2 + Accident-4 + Accident-6 + Accident-8
          -.0606      .0208        -.2885       -.07537      -.2858
          [-.274]    [.0936]      [-1.315]     [-.3435]     [-1.299]

          + Accident-10 + Accident-12 + Accident-14 + Accident-16
            -.3365        -.2646         -.00209       .471
            [-1.51]       [-1.19]        [-.00937]    [2.095]

          + Hearings  +  Time
            -.1275      -.06286
            [-.6565]    [-1.805]

Equation 7: Relation of 1981 Air Traffic Controllers and
            Air Traffic Control Related Accidents
R-square = .7411

ATC accidents = Strike + Time + Log(Time) + FAA ADs + log(FAA)
Coef.           .139E-7   .25E-6  -.207E-4   -.298E-8   .375E-6
[Tstat]         [.182]    [2.14]   [-2.36]    [-1.19]    [1.5]

             + Jet Innovation + Deregulation
                .578E-7          .588E-7
                [.67]            [.825]
```

CONCLUSIONS

Literature Survey

From the literature survey, it appears that accidents may be random or occur so infrequently that they approximate randomness, for lack of a better-fitting distribution. There is a size-safety relation, though it holds only across groups of carriers and is weak. Technological progress has steadily improved air safety, and deregulation does not appear to have hampered that time trend, and perhaps has improved it.

Probably the biggest contribution of this study was the debunking of the financials-safety myth. Deregulation has not caused cost-cutting to win out over reputation effects and endanger safety: in fact, the opposite appears true.

Regulation emasculated a strong public interest and safety discipline mechanism. Testimonies before and after deregulation indicate that before deregulation, passengers assumed all airlines were alike, presumably because they were all regulated alike. Since deregulation, passengers follow safety records and remember accidents.

Statistical Analysis

This inquiry developed a much-needed new definition of an accident useful to United States air travelers. This measure provides a purer, more error-free measurement of flight safety. Future studies should extend the meter to United States passengers on foreign and charter flights.

The safety rate was tested against departures and miles, rather than assuming one measure was best for all purposes. The effect of deregulation on load factors and death rate, long ignored, was tested and found to be insignificant.

Two data sets were collected and used with the new accident definition. Accidents are randomly generated but tend to occur more under certain circumstances. Deregulation was a positive safety innovation. Profit and maintenance expenditures have no uniform or significant effect on safety.

FAA has played a significant role in air traffic control innovation, though deregulation indicates that less government control is better. FAA exhibited decreasing returns to effectiveness statistically; other studies indicated that fines and regulations were statistically insignificant. A significant knee-jerk relation with Congress failed to appear. Assuming that ADs are a proxy for overall FAA activity, FAA has improved aviation safety, notably in its technology leadership.

Historical Observations

Civil Aeronautics Authority, Civil Aeronautics Board, and NTSB reports over 60 years point to certain factors correlating with higher accident rates. Rain, night flights, smaller planes, turboprops (as opposed to bigger jets), international flights, and territorial flights all increase risk.

The 1960s witnessed a high number of equipment failures, particularly landing gear collapse, with landings on foamed runways (see Figure 1). Midair collisions in the early 1960s occurred with frightening frequency, creating risk that dwarfs

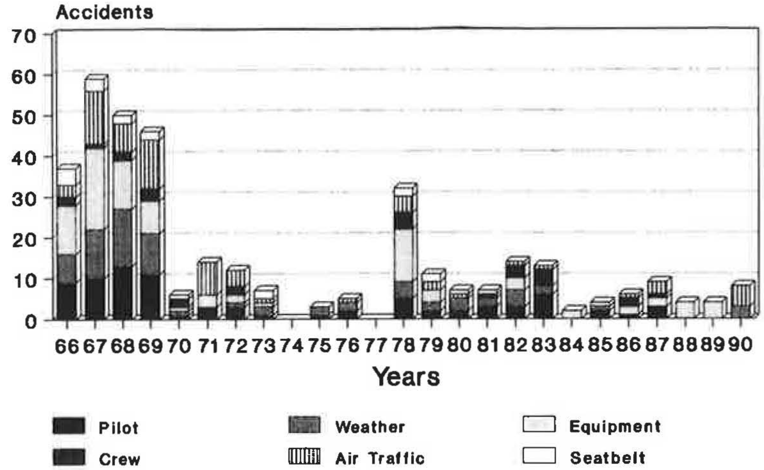

FIGURE 1 Accident causes over time.

the modern odds. Congestion and air traffic control error contributed to many of the 1960s collisions. The 1970s showed the rise and fall of unseated passenger and flight attendant injuries. The 1980s saw increasing crew communication and better and more aircraft equipment. The power of the time and technology trend lies in ongoing safety improvements.

Safety levels achieved in the 1960s made commercial flight in the 1930s appear reckless; similarly, 1990 safety levels make the 1960s flights appear dangerous. Paradoxically, because of deregulation, travelers are now more concerned with danger levels; that in turn raises vigilance. Deregulation may be seen as one in a set of continuing safety improvements. It is a sweet failing that these improvements make accidents so rare that it is hard to statistically prove that result.

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REFERENCES

1. J. Nance. Economic Deregulation's Unintended but Inevitable Impact on Airline Safety. In *Transportation Safety in an Age of Deregulation* (L. Moses and I. Savage, eds.). Oxford University Press, New York, 1989.
2. A. Chalk. Air Travel: Safety Through the Market. *Cato Policy Report*, Vol. 9, No. 4, July–Aug. 1987.
3. D. Golbe. Safety and Profits in the Airline Industry. *Journal of Industrial Economics*, March 1986, pp. 305–318.
4. N. L. Rose. Profitability and Product Quality: Economic Determinants of Airline Safety Performance. *Journal of Political Economy*, Nov. 1990, pp. 944–961.
5. A. Barnett and M. K. Higgins. Airline Safety: The Last Decade. *Management Science*. Jan. 1989, pp. 1–21.
6. A. Kanafani and T. Keeler. New Entrants and Safety. In *Transportation Safety in an Age of Deregulation* (L. Moses and I. Savage, eds.). Oxford University Press, New York, 1989.
7. C. Oster and J. S. Strong. The Worldwide Aviation Safety Record. *William and Mary Public Policy Conference: The Global Airline Industry: Future Directions, Future Policies*. Nov. 8–10, 1990.
8. C. V. Oster and C. K. Zorn. Is It Still Safe To Fly. In *Transportation Safety in an Age of Deregulation* (L. Moses and I. Savage, eds.). Oxford University Press, New York, 1989.
9. R. Golaszewski and E. Bomberger. Measuring Differential Safety Performance Among Air Carriers. *Transportation Research Forum*, I, pp. 12–21.
10. N. L. Rose. *Financial Influences on Airline Safety*. Sloan School of Management Working Paper. Massachusetts Institute of Technology, 1987.
11. R. Golaszewski. The Level of Risk in Air Transportation Versus Public Perceptions of Safety. ORSA/TIMS Joint National Meeting, Oct. 16–18, 1989, New York.
12. *Aircraft Accident/Incident Reports—Brief Format—Supplemental Issue*. Various issues. National Transportation Safety Board, 1966–1987.
13. H. Lefer. Changes Will Result From DC-10 Crash, But They Won't Be Big. *Air Transport World*, Oct. 1979, pp. 24–29.
14. T. G. Moore. The Myth of Deregulation's Negative Effect on Safety. In *Transportation Safety in an Age of Deregulation* (L. Moses and I. Savage, eds.). Oxford University Press, New York, 1989.
15. J. Lauber. Summary of Other Aviation Issues. In *Transportation Safety in an Age of Deregulation* (L. Moses and I. Savage, eds.). Oxford University Press, New York, 1989.
16. *Transportation Safety in an Age of Deregulation* (L. Moses and I. Savage, eds.). Oxford University Press, New York, 1989.
17. J. L. Gifford and P. Sinha. Airport Congestion and Near-Mid-Air Collisions. *Transportation Research*, Vol. 25A, 1991, pp. 91–99.
18. J. C. Panzar and I. Savage. Regulation, Deregulation, and Safety: An Economic Analysis. In *Transportation Safety in an Age of Deregulation* (L. Moses and I. Savage, eds.). Oxford University Press, New York, 1989.
19. S. Borenstein and M. B. Zimmerman. Losses in Airline Demand and Value Following Accidents. In *Transportation Safety in an Age of Deregulation* (L. Moses and I. Savage, eds.). Oxford University Press, New York, 1989.
20. Air Transport Association. *FAA Facts and Figures*. Washington D.C.: Air Transport Association.
21. *Annual Report to Congress*. National Transportation Safety Board, Various years.
22. J. Ott. Agency Reveals Plan To Focus Research on Long-Range Projects. *Aviation Week and Space Technology*, Dec. 12, 1988.