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REGULATORY IMPACT ANALYSIS

Flightcrew Member Duty and Rest Requirements
PART 117

NOTICE OF PROPOSED RULEMAKING

OFFICE OF AVIATION POLICY AND PLANS

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Executive Summary

This report documents a benefit/cost analysis of FAA's proposed amendments to its flight, duty and rest regulations applicable to certificate holders and their flight crew members. The proposal recognizes the growing similarities between the types of operations and the universality of factors that lead to fatigue in most individuals. Fatigue threatens aviation safety because it increases the risk of pilot error that can lead to an accident. The proposed requirements would eliminate the current distinctions between domestic, flag and supplemental operations. The proposal provides different requirements based on the time of day, whether an individual is acclimated to a new time zone, and the likelihood of being able to sleep under different circumstances.

FAA has determined the proposed rule: (1) has benefits that justify its costs, (2) is an economically "significant regulatory action" as defined in section 3(f) of Executive Order 12866, (3) is "significant" as defined in DOT's Regulatory Policies and Procedures; (4) would have a significant economic impact on a substantial number of small entities; (5) would not create unnecessary obstacles to the foreign commerce of the United States; and (6) would impose an unfunded mandate on the private sector.

Based on the FAA safety effectiveness assessment for this proposed rule to prevent pilot fatigue accidents, we estimate a total benefit of $659 million ($ million at present value, over 10 years). Our rule requirements began with the recommendation from labor and industry and we then applied fatigue science to maximize benefits relative to costs. The total estimated costs of the proposed rule over 10 years are $1.25 billion

($804 million at present value). There is over a 7 percent probability that undiscounted benefits of averting passenger airplane accidents would exceed $1.25 billion and over a 10 percent probability the present value of the benefits of averting cargo airplane accidents would exceed $804 million. The benefits from a single near-term prevented catastrophic accident of a common 150-passenger airplane with an average load factor would exceed the present value cost of this rule. If the value of an averted fatality were increased to $12.6 million, the present value of the benefits would equal the present value of compliance costs. The FAA invites comments on the methodology, data, and assumptions employed in this analysis.

	Nominal Costs	**PV Costs**
	(millions)	**(millions)**
Total Costs (over 10 years)	$1,254.1	$803.5
Benefits	**Nominal Benefits (millions)**	**PV Benefits**
		(millions)
$6.0 million VSL	$659.40	$463.80
$8.4 million VSL	$837	$589

Benefits Analysis

Background & History

The NTSB's list of Most Wanted Transportation Safety Improvements includes safety recommendations about pilot fatigue. These recommendations are based on accident investigations and an NTSB safety study on commuter airline safety. The first

NTSB recommendations to the FAA about pilot fatigue rulemaking occurred after the Guantanamo Bay, Cuba, accident on August 18, 1993. In that accident, three flight crew members were seriously injured and the airplane was destroyed. The captain lost control of the airplane while on approach to the U.S Naval Air Station at Guantanamo. The NTSB listed as a probable cause of the accident the impaired judgment, decision-making, and flying abilities of the captain and flight crew because of fatigue. The flight crew had been on duty for 18 hours and had flown for 9 hours. The NTSB recommended the FAA revise part 121 to require that "tail end" ferry flights be included in flight crews' flight time and duty time (A-94-105). The NTSB also recommended the FAA revise the flight/duty time limitations in its regulations to ensure the regulations incorporate the results of the latest research on fatigue and sleep issues (A-94-106).

The NTSB's list of Most Wanted Transportation Safety Improvements includes another safety recommendation on pilot fatigue and ferry flights conducted under 14 CFR part 91. On February 19, 1995, three flight crew members died after a Douglas DC–8–63 operated by Air Transport International was destroyed by ground impact and fire during an attempted three engine takeoff at Kansas City International Airport in Kansas City, Missouri. The NTSB noted the flight crew conducted the flight as a maintenance ferry flight under part 91 after a shortened rest break following a demanding round-trip flight to Europe that crossed multiple time zones. The NTSB further noted the international flight, conducted under part 121, involved multiple legs flown at night following daytime rest periods. In addition, the NTSB found the captain's last rest period before the accident was repeatedly interrupted by the certificate holder.

In issuing its 1995 recommendations, the NTSB stated the flight time limits and rest requirements under part 121 that applied to the flight crew before the ferry flight did not apply to the ferry flight operated under part 91. The NTSB found the regulations allowed a substantially reduced flight crew rest period for the nonrevenue ferry flight. Because of the investigation, the NTSB reiterated earlier recommendations to (1) finalize the review of current flight and duty time limitations to ensure the limitations consider research findings in fatigue and sleep issues and (2) prohibit certificate holders from assigning a flight crew to flights conducted under part 91 unless the flight crew meets the flight and duty time limits under part 121 or other applicable regulations (A–95–113). Since this recommendation there have been additional accidents in which flight crew fatigue was a contributing factor in the accident.

On July 26, 2002, a Federal Express flight 1478, B727-232F, struck trees on approach and crashed short on the runway at the Tallahassee Regional Airport, Tallahassee, FL. The NTSB determined that the probable cause of the accident was the flight crew's failure to establish and maintain a proper glidepath during the night visual approach to landing. The NTSB also determined that the captain's and first officer's fatigue contributed to the accident. Three flight crew members were seriously injured and the airplane was destroyed. The NTSB mentioned flightcrew fatigue as a factor contributing to the accident. In February 2006, the NTSB issued safety recommendations after a BAE–J3201 operated under part 121 by Corporate Airline struck trees on final approach and crashed short of the runway at Kirksville Regional Airport, Kirksville, Missouri. The captain, first officer, and 11 of the 13 passengers were fatally injured. The

NTSB determined that the probable cause of the accident was the pilots' failure to follow established procedures and properly conduct a nonprecision instrument approach at night in instrument meteorological conditions. The NTSB concluded that fatigue likely contributed to the pilots' performance and decision making based on the less than optimal overnight rest time available to the pilots, the early reporting time for duty, the number of flight legs, and the demanding conditions faced during the long duty day.

Because of these accidents, the NTSB issued the following safety recommendations related to flight and duty time limitations: (1) modify and simplify the flight crew hours-of-service regulations to consider factors such as length of duty day, starting time, workload, and other factors shown by recent research, scientific evidence, and current industry experience to affect crew alertness (A–06–10); and (2) require all part 121 and part 135 certificate holders to incorporate fatigue-related information similar to the information being developed by the DOT Operator Fatigue Management Program into initial and recurrent pilot training programs. The recommendation notes that this training should address the detrimental effects of fatigue and include strategies for avoiding fatigue and countering its effects (A–06–11).

There have also been some incidents in which the NTSB cited flight crew fatigue as a cause. On February 18, 2007, Delta Connection flight 6448, operated by Shuttle America, Inc., overran the runway at Cleveland-Hopkins International Airport, Cleveland, OH (no fatalities and no serious injuries). On April 12, 2007, Pinnacle Airlines flight 4712 overran the runway at Cherry Capital Airport, Traverse City, Michigan (no fatalities and no serious injuries). On February 13, 2008, Go! Flight 1002, operated by Mesa Airlines, flew past its destination airport at Hilo, Hawaii – the flight crew fell asleep while in-flight (no fatalities and no serious injuries).

The current FAA rules in part 121 do not prescribe duty limits; rather they focus on flight time limits and rest requirements. Flight time limits and rest requirements vary based on the type of operation. The requirements in these subparts apply to domestic, flag, and supplemental operations. Under the current rules for domestic operations, flightcrew members must receive at least an 8-hour rest period during the 24-hour period before the end of each flight. Flightcrew members conducting flights under part 121 for domestic operations are limited to 30 hours of flight time in any seven consecutive days. The 7-consecutive-day limit for flag operations is 32 flight hours, and there is no 7-consecutive-day limit for supplemental operations. In addition, part 121 limits the flight time of flightcrew members engaged in domestic operations to 1,000 hours in any calendar year. Flightcrew members engaged in flag and supplemental operations are limited to 1,000 hours in any 12-calendar-month period. There is a quarterly and semi-annual limit of 500 hours and 800 hours, respectively, for unscheduled operations. Operators are required to provide each crewmember a minimum of 24 consecutive hours of rest during any seven consecutive days for all domestic, flag, and supplemental operations conducted under part 121.

On June 10, 2009, Federal Aviation Administration (FAA) Administrator J. Randolph Babbitt testified before the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Aviation Operations, Safety, and Security on Aviation Safety on the FAA's role in the oversight of certificate holders. He addressed issues on flightcrew member training and qualifications, flightcrew fatigue, and consistency of safety standards and compliance between air transportation certificate holders. He also committed to assess the safety of the air transportation system and to take appropriate steps to improve it.

In June 2009, the FAA convened the Flight and Duty Time Limitations and Rest Requirements Aviation Rulemaking Committee (ARC). The FAA tasked the ARC to develop recommendations for an FAA rule based on current fatigue science and a review of international approaches to the issue. The ARC submitted its recommendations to the FAA on September 10, 2009.

Summary of Scientific Presentations

To achieve the goal of developing proposed rules to enhance flightcrew member alertness and employ fatigue mitigation strategies, the ARC reviewed scientific information presented by experts in sleep, fatigue, and human performance research. Below is a summary of the scientific presentations:

1. Fatigue

Fatigue is characterized by a general lack of alertness and degradation in mental and physical performance. There are three types of fatigue: transient, cumulative, and circadian. Transient fatigue is acute fatigue brought on by extreme sleep restriction or extended hours awake within 1 or 2 days. Cumulative fatigue is fatigue brought on by repeated mild sleep restrictions or extended hours awake across a series of days.

Circadian fatigue refers to the reduced performance during nighttime hours, particularly during the window of circadian low (WOCL).

There is no direct measure or physiological marker that shows when a person is fatigued, although biomedical data may indicate physiological conditions favorable to fatigue. Fatigue is often accompanied by drowsiness but is more than just being sleepy or tired. Common symptoms of fatigue include:

- Measurable decrease in speed and accuracy of performance,
- Lapses of attention and vigilance,
- Delayed reactions,
- Impaired logical reasoning and decision making, including a reduced ability to assess risk or understand effects of actions,
- Reduced situational awareness, and
- Low motivation to perform optional activities.

Various factors contribute to whether an individual experiences fatigue and the severity of fatigue experienced. The major factors affecting fatigue include:

- *Time of day*. Fatigue is, in part, a function of circadian rhythms. Human waking and sleep cycles follow a 24-hour cyclical wave pattern known as the internal body clock (circadian rhythm). The circadian rhythm is closely correlated to core body temperatures. All other factors being equal, fatigue is most likely, and, when present, most severe, during the WOCL, when body temperatures are at their lowest, during a four hour period between the hours of 12:00 AM and 6:00 AM. Studies have found that subjects remaining awake through the WOCL and into the daytime hours experience improvements in performance once past the WOCL, relative to their performance during the WOCL.
- *Amount of recent sleep.* If a person has had significantly less than 8 hours of sleep in the past 24 hours, he or she is more likely to be fatigued.
- *Time awake.* A person who has been continuously awake more than 17 hours since his or her last major sleep period is more likely to be fatigued.
- *Cumulative sleep debt.* Sleep debt refers to the impact of receiving less than a full night's sleep for multiple days. For the average person, cumulative sleep debt is the difference between the sleep a person has received over the past several days, and the sleep they would have received if they obtained 8 hours

of sleep per night. For example, a person who has received 10 hours of sleep over the past 2 nights has a cumulative sleep debt of 6 hours. A person with a cumulative sleep debt of more than 8 hours since his or her last full night of sleep is more likely to be fatigued.

- *Time on task.* The longer a person has continuously been doing a job without a break, the more likely he or she is to be fatigued.
- *Individual variation*. Different individuals will respond to fatigue factors differently. Different individuals may become fatigued at different times, and to different degrees of severity, under the same circumstances.

There often is interplay between various factors contributing to fatigue. For example, the performance of a person working night and early morning shifts is impacted by the time of day. Also, because of difficulty in obtaining normal sleep during other than nighttime hours, such a person is more likely to have a cumulative sleep debt or to not have obtained a full night's sleep within the past 24 hours.

2. Fatigue in Aviation

Several aviation-specific work schedule factors[1] can affect sleep and subsequent alertness. These include early start times, extended work periods, insufficient time off between work periods, insufficient recovery time off between consecutive work periods, amount of work time within a shift or duty period, insufficient time off between work periods, number of consecutive work periods, night work through one's window of circadian low, daytime sleep periods, and day-to-night or night-to-day transitions.

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[1] Rosekind, MR. Managing work schedules: an alertness and safety perspective. In: Kryger MH, Roth T, Dement WC, editors. Principles and Practice of Sleep Medicine; 2005:682.

3. Preventing and Mitigating Sleep Debt

Scientific research and experimentation has consistently showed that adequate sleep sustains performance. For most people, 8 hours of sleep in each 24 hours sustains performance indefinitely. Sleep opportunities during the WOCL are preferable, although some research suggests the total amount of sleep obtained is more important than the timing of sleep within the day. When a person has accumulated a sleep debt, recovery sleep is necessary. Recovery sleep requires an opportunity to obtain enough sleep to fully restore the person's "sleep reservoir." Recovery sleep should include at least one physiological night, that is, one sleep period during nighttime hours in the time zone in which the individual is acclimated. Recovery sleep does not require additional sleep equal to the cumulative sleep debt; that is, an 8-hour sleep debt does not require 8 additional hours of sleep. However, sleep on recovery days should be extended beyond the usual sleep amount. The average person needs over 9 hours of sleep per night to recover from a sleep debt.

This analysis looks at the projected costs and benefits of the FAA's NPRM on flight duty and rest requirements for flightcrew members of air carriers in part 121. The proposal is primarily based upon the work and discussions within the ARC along with the NTSB recommendations. For the detailed discussion of the proposal and the discussion of the exact requirements the reader should see the NPRM that is filed in the docket.

Benefits

The scientific community recognizes there is a complex relationship between pilot performance and safety risk, and how the performance is impacted by pilot schedules. Investigations of pilot work variables have explored how they affect crewmember alertness, how alertness affects crew performance under differing workloads and operational environments, and how pilot work variables and alertness combine to affect safety performance that is measured by accidents and incidents.[2]

In 1980, in response to a congressional request, the NASA Ames Research Center created a Fatigue/Jet Lag Program to study fatigue. In a Technical Memorandum in 1995, the Center concluded the average sleep requirement is 8 hours in a 24-hour period.[3] As another example, a study by Rosekind and others states that most humans need about eight hours of sleep per night.[4] In addition, Battelle Memorial Institute reviewed the scientific literature on fatigue in a study for the FAA. This review found that most researchers recommend an adult needs an average of 7.5 to 8 hours sleep a day. The available scientific literature has identified several symptoms that indicate the presence of fatigue, including: increased anxiety, decreased short-term memory, slowed reaction time, decreased work efficiency, decreased vigilance, and increased errors.

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[2] Battelle Memorial Institute, JIL Information Systems, " An Overview of the Scientific Literature Concerning Fatigue, Sleep, and the Circadian Cycle," January, 1998, prepared for the Office of the Chief Scientific and Technical Advisor for Human Factors, Federal Aviation Administration.

[3] Principles and Guidelines for Duty and Rest Scheduling in Commercial Aviation, NASA Technical Memorandum, 1995.

[4] Rosekind, Neri and Dinges, "From Laboratory to Flightdeck: Promoting Operational Alertness" in Fatigue and Duty Limitations—An International Review, (download 1-25-99, http/olicas.arc.nasa.gov/Zteam/FCP/subs/raes.html), page 1.

Benefit Overview

The approach of this benefits analysis begins with a search of the historical record of accidents to establish the extent of the fatigue problem. First, there is some evidence that pilots are knowingly flying tired or should know that they are flying tired. Since 1990, the NTSB has identified five pilot error accidents in which lack of adequate sleep was a contributing factor in causing the accident. Second, comparing pilot error accidents to length of pilot duty periods indicates that pilot error accidents are more likely to occur after long periods on duty. We have calculated the increased accidents occurring late in duty periods. Third, if the duty period begins late in day, then pilots might be tired even though they are at the beginning of their duty period. We have found accidents where this was the case. Fourth, there is also evidence in the accident record where chronic fatigue may have been a contributing factor to the accident. Last, the accident rate for takeoffs and landings that occur between midnight and 6:00 am is much higher than the accident rate for those operations that occur during the day time. We have calculated the increased accidents that occur between midnight and 6:00 am.

Having projected the possible extent of fatigue based on the historical record, we estimate the likelihood of accidents happening in the future using simulation techniques. We also use simulation techniques to estimate future casualties, which we monetize. In this way, we estimate the potential benefits of the proposed rule.

. Finally, we model risk of fatigue for current pilot schedules, and compute the number of hours in higher risk categories with and without the rule. The projected reduction in fatigue exposure is corroborating evidence supporting this proposal.

Receive Adequate Rest (Sleep) Between Duty Periods

One of the goals of this rulemaking is to require part 121 operators to provide flightcrew members the opportunity to acquire an adequate rest before the start of their flight duty period. In the past 20 years, there have been at least five accidents where the flightcrew members did not have an adequate amount of sleep prior to the start of their flight duty period.

The first accident in the 20-year analysis period occurred at Pine Bluff, AR at 3:55 PM on April 29, 1993. An Embraer EMB120 RT, Brasilia, N24706, (operated by Continental Express, Inc.) was substantially damaged when it collided with rough terrain during an overrun following a forced landing. The forced landing was executed following a stall and loss of control at 17,412 feet during climb. After regaining control of the airplane the flightcrew noticed that the left engine nacelle was damaged and that three propeller blades were missing. The airplane was unable to maintain level flight. After the flightcrew landed the airplane, it hydroplaned off the wet runway. The airplane was substantially damaged as a result of overrunning the runway. There were three crewmembers and 27 passengers on board the airplane. The flight attendant and 12 passengers received minor injuries; the others were uninjured. The NTSB determined that pilot error was the cause of the accident.

Contributing to the accident was fatigue induced by the flightcrew's failure to properly manage their provided rest periods. The flightcrew got off duty at 11:30 AM the day before the accident. The captain went to bed between midnight and 12:30 AM and awoke about 5:00 AM (receiving only 4 ½ to 5 hours sleep) for a departure at 6:30 AM. The first officer went to bed between 11:00 PM and midnight and woke up about 4:30 AM (receiving between 5 and 5 1/2 hours sleep). Both pilots claimed they felt well rested prior to starting their flight duty for that day. The accident flight occurred during the seventh and last flight of the day.

The second accident occurred at 10:27 PM on February 16, 1995 at Kansas City, MO. A Douglas DC-8-63, N782AL, operated by Air Transport International (ATI), was destroyed by ground impact and fire. The accident occurred during a three-engine takeoff for a ferry flight under Part 91. Three crew members were fatally injured. The NTSB determined that the accident was due to pilot error.

In addition to being inadequately trained, the flightcrew was suffering from fatigue as a result of limited opportunities for rest, disruption of their circadian rhythms, and lack of sleep in the days prior to the accident. Before their assignment to the accident trip, the flightcrew had completed a demanding round-trip to Europe. The flights crossed multiple time zones (12 in all) in a short period of time. The Dover-Ramstein-Gander-Dover legs were flown at night following daytime rest periods, which disrupted the flightcrew's circadian rhythms. On the day of the accident, the flightcrew had checked into a hotel in Dover, DE, at 2:40 AM EST. The captain placed a short call from his room at 3:14 AM. At 8:02 AM (receiving not quite 5 hours sleep), he called home and spoke to his wife for 25 minutes. ATI Scheduling called the captain at 10:30 AM. There were other calls between ATI and the captain throughout the day (10:45 AM, 12:44 PM, 2:00 PM, and 2:10 PM). The flightcrew departed Dover at 3:18 PM EST and arrived at Kansas City at 5:39 PM CST.

The flightcrew was required to take a 16 hour rest period before they could be assigned any additional part 121 duties. However, there are no flight time limits or rest requirements for Part 91 ferry flights that follow Part 121 revenue flights. So 12 hours after checking into a hotel at Dover, the flightcrew checked out to assume duty under Part 91 ferry flight rules.

The third accident in the 20-year analysis period occurred on May 8, 1999 at 7:01 AM EST. A Saab-Scania AB (Saab), N232AE, operated by American Eagle Airlines, INC., overran the runway at John F Kennedy International Airport, Jamaica, NY. The captain conducted an ILS approach with excessive altitude, airspeed, and rate of descent, while remaining above the glide slope. The airplane landed 7,000 feet beyond the approach end of the runway, at excessive speed (157 knots), and overran the runway. One passenger was seriously injured while exiting the airplane, the other passengers and crewmembers were uninjured. The airplane was substantial damaged by the accident.

The NTSB determined that pilot error caused the accident. During the post accident interviews, both pilots stated that they were fatigued. The flightcrew was working a continuous duty overnight schedule. The previous day, they both woke up during the morning, did not sleep during the day, and reported for duty at 11:00 PM for a flight scheduled at 11:46 PM. The day before the accident, the flight was delayed and arrived at BWI around 1:00 AM. They got to sleep around 1:30 AM and awoke at 4:45 AM for the accident flight, which was scheduled to depart at 6:10 AM.

The fourth accident occurred at Tallahassee, FL on July 26, 2002 at 5:37 AM EST. A Boeing 727-23F, N497FE, operated by Federal Express (FedEx) struck some trees and landed short of the runway. All three flightcrew members were seriously injured. The airplane was destroyed by impact and the resulting fire. The NTSB determined that the accident was caused by pilot error. Both the captain and the first officer were fatigued at the time of the accident. The captain had only 3 ½ hours of sleep prior to the accident. He had disturbed, interrupted sleep on the two previous nights. The first officer, who was on reserve duty, reported that he was having difficulty adjusting his sleep cycle to the reserve-duty schedule. His reserve-duty schedule caused him to frequently change his sleep pattern between sleeping during daytime hours and night hours. He had approximately 5 to 6 hours sleep before reporting for duty. The flight engineer had received about 6 ½ hours sleep before he began his duty and had taken two naps (30 minutes on a commute to Memphis, TN, and 30 to 60 minutes at FedEx's crew rest facility at Memphis airport).

The fifth accident occurred at 3:06 PM EST on February 18, 2007 at Cleveland, Ohio. An Embraer ERJ-170, N862RW, operated by Shuttle America, Inc. as Delta Connection flight 6448, landed during snow conditions and overran the end of the runway. Three passengers received minor injuries; the remaining 68 passengers and 4 crew members were uninjured. The NTSB determined that the accident was caused by pilot error. Contributing to the accident was the captain's fatigue.

On the day of the accident the captain had received only 45 minutes to an hour of sleep. The captain had reported that he was too tired to fly on July 30, 2006. The Shuttle America chief pilot and ERJ-170 program manager told him fatigue calls made outside duty times would result in an unavailable attendance mark. On January 16, 2007 Shuttle America notified the pilot in writing that his attendance had reached an unacceptable level – nine absences occurrences (seven sick and two unavailable attendance marks) totaling 18 days within the previous 12 months – and that future occurrences would result in corrective action, which could include termination from the company. According to company policy eight absence occurrences would result in termination. Since the captain had not received any previous notification from Shuttle America about his attendance record he had not yet been terminated. The captain stated that he did not cancel his trip due to fatigue because he thought he would be fired.

In the five accidents discussed above, the captains (and sometimes the other flightcrew members) were operating their airplanes while they were fatigued and they knew that they were fatigued (or should have known that that they were fatigued). The new requirements of this rulemaking, including increased training, would prevent these accidents from happening in the future.

Duty Time Limits

In analyzing this rulemaking action, the FAA conducted an assessment of the risks of pilot work practices and the risk of a part 121 accident.[5] Human factors-related accidents from the 1990 to 2009 time period were identified that involved, at a minimum, substantial damage to the aircraft or serious injuries to those on-board. All turbulence-related accidents were excluded, as were accidents that did not have a 72-hour history of pilot activities before the accident. There were 43 accidents where the needed data were available (sometimes slightly more or fewer than 43 accidents depending on the schedule-related risk factor of interest). The FAA believes that these accidents are representative of all the major human factor-caused accidents that occurred during the period, including all accidents where fatigue was a factor.

As part of the analysis for this rulemaking, the FAA obtained data on pilot work patterns from six carriers covering two months of actual flight activity during 2009. The six carriers that provided flight crew duty schedule data included three large legacy passenger carriers that conduct both international and domestic operations (one of which includes elements of a low cost domestic carrier and two large cargo carriers that conduct both international and domestic air cargo services. For the following analysis, these data were used to create profiles of the work patterns of the pilots from these six airlines. The data were converted (for each month) into one record for each pilot with a line of actual flying for one or both of the months. Each pilot record tracked a pilot's activity for every

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[5] GRA, Incorporated, "Flight and Rest Time Safety and Cost Analyses (Phase 3)," October 30, 2000, prepared for FAA, Office of Aviation Policy and Plans under Work Order No. 1, Contract No. DTFA01-98-C-00096.

hour in the entire month that the pilot was on duty. The beginning and end of each trip segment were recorded for each pilot and put into a database. Parameters of interest were then calculated such as the length of duty periods, the day within a duty trip on which duty hours take place and the numbers of takeoffs and landings within a duty period. The analysis tracked these activities in base time (defined as the time at the location where the pilot began a multi-day trip, which is often the pilot's crew base). The analyses provide support for regulatory proposals to govern duty time.[6] Specifically, it was found that the

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[6]

It is important to note that pilots are only at risk of suffering an air accident during those duty hours when they are actually operating an aircraft. Therefore, the first hour of a pilot's duty day – spent (as indicated by industry practice and the data provided by carriers for this analysis) engaged in ground activities such as check in, flight and schedule information acquisition and pre-departure inspections of aircraft – does not represent duty time "at risk" of an air accident. Similarly, once each pilot has concluded the first flight segment of his or her duty day, some percentage of the pilot's duty time is spent on the ground between actual flight segments. This time spent on duty but on the ground is also duty time that is not "at risk" of an air accident. After adjusting for the first duty hour, about 75 percent of pilot duty hours are spent operating an aircraft and thus "at risk" of an air accident. For the statistical analyses presented below, the pilot duty time data has been adjusted to reflect this. Adjustments are done on the reported pilot duty data in the following way.

- The first hour of the pilot duty day is excluded, since it is not an hour of duty "at risk" of an air accident
- After this first hour each pilot begins his or her first flight segment of the day. The length of this first flight segment varies from pilot to pilot, depending on the day's itinerary. Therefore the second duty hour of each pilot's duty period is treated as if it is an "at risk" duty hour for each pilot, so the total number of second duty hours is not adjusted in any way.
- During the third through eighth duty hours, some pilots are at times on the ground between segments (and thus are not "at risk"), some have resumed flying their second, third, fourth or greater flight segment of the day (and are therefore "at risk"), some continue to fly throughout a long first flight segment of the day (and are therefore "at risk"), and so forth. Over these hours of the duty period, individual pilots spend some duty time on the ground and not "at risk" and the remainder of the duty time operating an aircraft and therefore "at risk." It is not possible to capture the actual variability in

proportion of accidents is higher for more lengthy duty periods than is the proportion of lengthy duty periods in the pilot sample. This is illustrated in Table 1 where about 6 percent of pilot duty hours are in the 11th or greater hour of a duty period while 16 percent of accidents that occur happen in the 11th or greater hour of the pilot's duty period. Similarly, nine percent of the accidents occur when a pilot has been on duty for 13 or more hours whereas just a little over one percent of pilot duty hours occur during that time. This analysis points to increased accident risk with increased duty time, even though pilot scheduling was not cited as a factor in all 43 accidents.

This analysis is also consistent with a study of pilot deviations by duty time within the past 24-hours (see Appendix A). In this study the portion of pilot deviations was greater than the exposure portion when duty time exceeded 6 hours during the past 24-hours. These findings and the analysis above suggest that more stringent limits on pilot duty time would be appropriate.[7]

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the pilot duty data, so for the third, fourth, fifth, sixth, seventh and eighth duty hours, the reported duty hour counts are reduced by 30 percent to account for this "sometimes 'at risk,' sometimes not 'at risk'" nature of this portion of the duty day. (This 30 percent adjustment factor for those hours of the duty period exceeds the observed 25 percent difference between flight time and duty time because no adjustment is made to the duty hours observed in the final hours of pilot duty periods.)

- For the ninth and greater duty hours in the pilot duty day, it is assumed that all pilots still on duty have commenced and are completing their final flight segment of the day, and are therefore "at risk" of an air accident during these duty hours.

The adjusted exposure data set is reported in Table 1 and is used for calculations reported in Table 2.

[7] It also should be noted that many union contracts today require periods of flight time, duty time, and rest time which are more stringent than the requirements established by the existing, and in some cases the proposed, Federal Aviation Regulations. However, our analysis is based on a mix of carriers including those with more stringent contracts.

Table 1: Captain Duty Hours and Accidents by Hour in Duty Period

Hour in Duty Period	Captains' Hours	Exposure Percentage	Accidents	Accident Percentage	Accident Proportion Relative Exposure Proportion
2nd	192,786	19%	7	16%	0.88
3rd – 4th	310,045	30%	8	19%	0.62
5th – 6th	211,474	20%	6	14%	0.69
7th – 8th	152,671	15%	11	26%	1.74
9th – 10th	108,084	10%	4	9%	0.89
11th – 12th	53,611	5%	3	7%	1.40
13th – 14th	10,010	1%	1	2%	2.33
15th +	1,003	<1%	3	7%	72.32
Total	***1,039,684***		***43***		

It is possible to estimate the number of accidents that could have been avoided by limiting the duty time of pilots using the information in Table 2. If fatigue was not a contributing factor in the 36 accidents that occurred during one of the first ten hours of pilot duty, then the relationship between the exposure data compiled for captains and the "normal" frequency of occurrence of serious accidents can be estimated as 3.69 accidents per 100,000 hours of duty time.[8] There were 53,611 hours of duty in the exposure data set that occurred during the 11th and 12th duty hour of a pilot's duty period; and based on

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[8] To calculate the factor for accidents per 100,000 hours of exposure data, the total number of duty hours in the exposure data in the tenth hour of a duty period and earlier is calculated, as [(192,786 + 310,045 + 211,474 + 152,671 + 108,084) = 975,060 duty hours] . Of the accidents, 36 occurred while the pilot was in the tenth or earlier hour of a duty period. This accident number of 36 divided by the exposure total of 975,060 hours results in an accidents-per-100,000 exposure hours ratio of 3.69.

the calculated frequency relationship (3.69 accidents per 100,000 hours of duty time) 1.98 accidents would be expected to occur, and three accidents did occur during those hours of a pilot's duty period. In the 13th and 14th duty hour there were only 10,010 hours of duty. The expected number of accidents at the above rate would be 0.4 for that time period, while one accident occurred involving a pilot in that range of the duty period length. Since there were only 1,003 hours of duty occurring in the 15th and greater hours of duty, only 0.1 accidents would be expected during those hours of the duty period. In the dataset there are three accidents involving a pilot with a duty period of this length.

Table 2 shows the projected number of accidents estimated in this way in comparison with the actual number of accidents. The difference between the actual number of accidents and the projected number of accidents would be the number of accidents that may be avoided for that time in duty period category. For example, in the 11th and 12th hour, there were three accidents,[9] and 1.98 was projected to occur; so there is a difference of 1.02 accidents. Similarly, in the 13th and 14th hour, there was one accident,[10] while only 0.4 were projected to occur; the difference (or possible number of accidents avoided) is 0.6 accidents. Finally, in the 15th and greater hours of duty, there were three accidents,[11] while only 0.1 were projected to occur based on the distribution of duty hours; the difference (or possible number of accidents avoided) is 2.9 accidents.

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[9] Hyannis, MA (1/23/99), Oshawa, Canada (12/16/2004 and Laramie, WY (2/18/07).

[10] Little Rock, AR (6/1/99).

[11] Guantanomo Bay (8/18/93), Kirksville, MO (10/19/04), and Traverse City, MI (4/12/07).

Table 2: Projected Number of Accidents Avoided by Limiting Duty Time

Hour in Duty Period	**Projected Number of Accidents**	**Actual Number of Accidents**	**Possible Accidents Avoided**
2nd	7.12	7	
3rd – 4th	11.45	8	
5th – 6th	7.81	6	
7th – 8th	5.64	11	
9th – 10th	3.99	4	
11th – 12th	1.98	3	1.02
13th – 14th	0.37	1	0.63
15th +	0.04	3	2.96
Total	***36.4***	***43***	***4.61***

A rule that limits duty time to 14 hours could avoid 2.96 accidents. If the limit on duty time were set at 12 hours, then 3.6 accidents could be avoided. If the limit on duty time were set at 10 hours, then 4.6 accidents could be avoided.

In Appendix B, two methods were used to test the statistical significance of the relationship between length of duty time and accidents. Both tests showed that the relationship was statistically significant. The FAA requests comments on the content of Appendix B.

Since 1990, there have been seven serious accidents where pilot fatigue due to a long duty period was a contributing factor. These accidents resulted in 24 fatalities to passengers and crew members, 52 serious injuries to passengers and crew members, and

65 minor injuries to passengers and crew members. There were also 76 passengers and crew members in these seven accidents who were not injured.

The first accident occurred on August 18, 1993, when a Douglas DC-8-61 freighter operated by American International Airways collided with level terrain short of the runway at Leeward Point Airfield, Guantanamo. The accident happened at 1656 EDT when the pilot lost control of the airplane while on approach. All three crew members were seriously injured and the airplane was destroyed. The NTSB determined that pilot error was the probable cause of the accident and that pilot fatigue was a contributing factor.

This is the first Part 121 accident where NTSB cited pilot fatigue as a contributing factor. At the time of the accident, the flight crew had been on duty for about 18 hours. On the day of the accident, the captain had been awake for over 23 hours with only five hours of sleep prior to waking up. The first officer had been awake 19 hours with 8 hours of sleep, and the flight engineer had been awake 21 hours with 6 hours of sleep. The day before the accident, the captain and first office had only two hours of sleep prior to being awake for over 17 hours.

The second accident occurred on January 22, 1999, when a Beech 1900D operated by Colgan Air, Inc. was substantially damaged while landing at Barnstable Airport, Hyannis, MA. The accident happened at 1719 EST. There were no injuries to the two crew members and the two passengers. The NTSB determined that pilot error was the probable cause. On the day of the accident the captain had reported for duty at 535 EST. At the time of the accident the captain had been on duty almost 12 hours.

The third accident occurred on June 1, 1999, when a McDonnell Douglas DC- 9-82 (MD-82) operated by American Airlines crashed after it overran the end of runway during a landing at Little Rock National Airport, Little Rock, AR. The accident happened at 2350 CDT. At the time of the accident there were thunderstorms in the airport area and the runway was wet. The captain and 10 passengers were fatally injured; four crew members and 41 passengers were seriously injured, one crew member and 64 passengers received minor injuries; and 24 passengers were uninjured. The airplane was destroyed by impact and a postcrash fire. The NTSB determined that pilot error was the probable cause and that fatigue was a contributing factor.

On the day of the accident, the captain awoke at 715 and reported for duty at 1038. At the time of the accident he had been awake for over 16 hours and had been on duty for over 13 hours. The first officer had also been awake for over 16 hours and on duty for over 13 hours.

The fourth accident occurred on October 19, 2004, when a BAE-J3201 operated by Corporate Airlines as an American Connection struck some trees on final approach to Kirksville Regional Airport, Kirksville, MO and crashed short of the runway. The accident occurred at 1937 CDT. The crew and 11 passengers were fatally injured and two passengers received serious injuries. The airplane was destroyed by impact and post crash fire. The NTSB determined that pilot error was the probable cause of this accident and that fatigue was a contributing factor.

On the day of the accident, the pilots were flying their sixth flight of the day and had flown 6 hours and 14 minutes when the accident occurred. They had also been on duty for 14 hours and 31 minutes at the time of the accident. The night before the accident, the captain had not slept well and awoke with a headache, according to his fiancée who talked with him during the morning by telephone.

The fifth accident occurred on December 16, 2004, when a Short Brothers SD3-60 aircraft operated by Air Cargo Carriers, Inc. as a chartered cargo flight attempted a landing at the Oshawa Municipal Airport, Oshawa, Canada. The crew rejected the landing after noticing poor breaking action and tried to conduct a go-around. After becoming airborne the aircraft crashed after striking the airport boundary fence. The accident happened about 2000 EST. The two pilots received serious injuries and the aircraft was substantially damaged. The Transportation Safety Board of Canada determined that pilot error was the probable cause of the accident.

The captain of the aircraft had been awake for 13 hours and had been performing duties as a flight crewmember for 10 hours before the accident. The captain was flying the aircraft at the time of the accident. The first officer had been awake for 12 hours and had been performing the duties as a flight crewmember for nine hours.

The sixth accident occurred on April 12, 2007, when a Bombardier/Canadair Regional Jet (CRJ) CL600-2B19 operated by Pinnacle Airlines ran off the departure end of runway 28 after landing at Cherry Capital Airport, Traverse City, MI. The accident occurred at 0043 EDT. There were no injuries, but the airplane was substantially damaged. The NTSB determined that pilot error was the probable cause of the accident and that fatigue was a contributing factor.

On April 11, the captain awoke about 0700 CDT and ate breakfast at the hotel. Both the captain and first officer left the hotel at 0800 CDT taking a shuttle to the airport. Both started their duty day at 0900 CDT on April 11, 2007. At the time of the accident both crew members had been on duty for 15 hours and 43 minutes (and the captain had been awake for over 17 hours.

The seventh accident occurred on June 20, 2007, when a Beech 1900D operated by Great Lakes Air ran off the runway after landing at Laramie Regional Airport, Laramie, WY. The accident occurred at 1620 MDT. There were no injuries, but the aircraft was substantially damaged. The NTSB determined that pilot error was the probable cause of the accident.

On the day of the accident, the captain and first officer were on the third day of a three day trip. The crew started their duty period at 0520 MDT. At the time of the accident, they had been on duty for 11 hours.

These seven accidents resulted in 24 fatalities to passengers and crew members, 52 serious injuries to passengers and crew members, and 65 minor injuries to passengers and crew members. There were also 76 passengers and crew members in these seven accidents who were not injured.

Time Awake

While being on duty a long time can be fatiguing, simply being awake a long time (approximately 17 hours or more) can also be fatiguing. In some accidents, the pilots had been on duty less than 10 hours, but those hours occurred late in the day and one or more of the flight crewmembers had been awake close to 17 hours or more. In the three accidents described below, statements of probable cause indicated crew performance but in each case one or more of the flight crewmembers had been awake a long time. These three accidents resulted in 245 fatalities on board the airplane and one fatality on the ground. There were also 20 seriously injured passenger and crew members, and three crew members and a passenger that received minor injuries.

The first accident occurred on July 2, 1994, when a DC-9-31 airplane operated by USAir, Inc. collided with tree and a private residence near Charotte/Douglas International Airport. This accident occurred at about 1843 EDT shortly after the flightcrew executed a missed ILS approach. There were 37 passenger fatalities, 16 passenger and crew received serious injuries, and 4 crew and a passenger received minor injuries. The airplane was destroyed by impact and a postcrash fire. The NTSB determined that pilot error was the probable cause of the accident.

Fatigue likely affected the performance of the first officer, who was the pilot-flying on the accident leg. The captain, who was off-duty the preceding 3 days, was less vulnerable to fatigue, but he too had already had a long day. The accident occurred 14 hours into the captain’s day. He had risen at 0455, drove to Dayton from his home, then flew to Pittsburgh to begin his duty day. The accident occurred at 1843, at the end of the third of 4 scheduled legs.

The first officer was more vulnerable to fatigue. He was on a four-day trip. On July 30, he ended his duty day at Tri-City Regional Airport, Biountville, Tennessee, where he had arrived at 2230. The NTSB report does not state when that duty day began, nor when the first officer awoke that day. However, after having a light meal, he went to bed at 0130. On July 1, he awoke at 0900. His duty day ended July 1 in Saint Louis at 2040 EDT. He went to bed at 2230 and awoke at 0615 on the accident day. He reported for duty at St. Louis for a flight to Pittsburgh. That flight, with the first officer as the pilot flying, departed at 0810. At Pittsburgh, the first officer joined the captain and they began their pairing. Like the captain, the first officer was nearly 14 hours into his day when the accident occurred. He was the pilot flying on the PIT-LGA leg and on the accident flight from CAE.

The second accident occurred on December 20, 1995, when a Boeing 757-223 operated by American Airlines crashed into mountainous terrain while on descent from cruise altitude in an attempt to land at Alfonso Bonilla Aragon International Airport in Cali, Columbia. The accident occurred at 2142 EST. There were 160 passenger and crew fatalities; only four passengers survived the accident with serious injuries. The airplane was destroyed by impact. The Aeronautica Civil of the Republic of Columbia determined that the probable cause was pilot error.

The accident flight was the first flight for both pilots after several days off. The captain arose at 0500 after a bit more than 7 hours of sleep. The first officer awoke at 0700. Both pilots appeared well rested. Both pilots reported to the operations manager at Miami more than an hour before their scheduled departure time of 1640. However, departure from the gate was delayed until 1714, followed by a lengthy ground delay due to ramp congestion.

It is reasonable to assume that the crew would have been tired at the time of the accident, despite this flight's being the first of their duty tour. The captain had been awake close to 17 hours, while the first officer had been awake 15 hours.

The third accident occurred on February 12, 2009, when a Bombardier DHC-8-400 operated by Colgan Air, Inc. as a Continental Connection flight crashed into a residence in Clarence Center, NY while on approach to Buffalo-Niagara International Airport, Buffalo, NY. The accident occurred at 2217 EST. The crew and passengers (49 people) were all killed and one person on the ground was also killed. The airplane was destroyed by impact and a postcrash fire. The NTSB identified probable cause and contributing factors as follows:

Both pilots performance was likely to have been impaired due to fatigue. Both pilots were based at Newark and both commuted. The captain lived near Tampa, FL and the first officer lived near Seattle, WA. Neither had a "crash pad" in Newark and both regularly used the crew room for sleeping. The captain often tried to bid trips that would ensure some nights in hotels at out-stations. In Newark, he sometimes stayed with a friend but usually slept in the crew room. The first officer always slept in the crew room when in Newark and told several people she had no need for a crash pad because "one of the sofas in the crew room has my name on it."

The duty tour began on February 10 for the recently upgraded captain. He commuted to EWR on February 9 from his home near Tampa, arriving at EWR at 2005. He apparently spent the night in the crew room. Multiple phone records and log-ins to the company's crew tracking system indicate he got little sleep before reporting for duty at 0530 on February 10. The captain then flew 3 flights and arrived at BUF at 1300. He spent the rest of the day in a hotel. On February 11, he left the hotel at 0515 to report for duty at 0615. Again the captain flew 3 flights and terminated his duty day at EWR at 1544. He apparently spent the rest of the day and that night in the crew room, where he was seen sleeping at 0630 on February 12, the day of the accident. Again, however, multiple phone records, log-ins to the crew tracking system, and contact with other employees indicate he got very limited sleep before reporting for duty at 1300.

The first officer commuted to EWR from SEA the day before the accident. She awoke on February 11 at 0900 and arrived at the airport at 1730 for a FedEx flight to MEM. The aircraft arrived in MEM at 0230 EST (2230 PST). She was said to have had about 90 minutes of sleep on the flight. She then took another flight to EWR, departing MEM at 0418 and arriving at EWR at 0623. She apparently slept for much of that two-hour flight. Upon reaching EWR, she spent the day in crew room, where she was seen napping. However, multiple phone records and log-ins to the company's crew tracking system indicate she got little sleep before reporting for duty at 1300.

The NTSB did not cite fatigue as a cause or as a factor. However, in its findings and conclusions, NTSB noted that the performance of both pilots "was likely impaired because of fatigue, but the extent of their impairment and the degree to which it contributed to the performance deficiencies that occurred during the flight cannot be conclusively determined."

NTSB added that both pilots failed to manage their off-duty time and commute responsibly and both failed to ensure that they remained "fit for duty."

The Captain was near the end of his fourth day since awakening on February 9. He had the opportunity for quality sleep only on the night of February 10, and that was cut short with a departure from the hotel at 0515 the next morning. Both pilots essentially stayed up all night on February 11, with no opportunities for deep sleep, and then found themselves operating a late-night flight after a day of cancellations and delays.

These three accidents resulted in 245 fatalities on board the airplane and one fatality on the ground. There were also 20 seriously injured passenger and crew members, and three crew members and a passenger that received minor injuries.

Chronic Fatigue

Chronic fatigue can happen to a flight crewmember, if his or her duty periods covers several days of night flying, or several days of multiple time zone changes, or several days with a heavy schedule. Chronic fatigue could be a contributing factor to accidents where pilot error was the probable cause of the accident. In the two accidents described below, the NTSB determined that pilot error was the probable cause, but in each case one or more of the flight crewmembers was subject to chronic fatigue. These two accidents resulted in two passengers who were seriously injured, and 38 crew members and a passenger who received minor injuries.

The first accident occurred on April 14, 1993, when a DC-10-30 operated by American Airlines overran runway 17L following a landing at Dallas/Fort Worth International Airport. The accident happened at 0659 CDT. It was raining at the time of the accident and there were numerous thunderstorms in the airport area. The airplane sustained substantial damage. There were no fatalities, but two passengers received serious injuries, and 38 passengers and crew members received minor injuries. The NTSB determined that the probable cause was "the failure of the captain to use proper directional control techniques to maintain the airplane on the runway."

Though the accident occurred just 46 hours into the crew's duty tour, the crew was completing its second consecutive day of disrupted circadian rhythms. The crew likely had awoken no later than 0600 CDT in order to reach DFW and report for duty in advance of their first flight at 0900 from DFW to Honolulu (HNL). After a 10-hour duty day, the crew arrived at HNL at about 1900 CDT (1400 HAST) and began their sleep period around 2200 HAST, awakening around 0700 HAST, with additional naps of various lengths from 1600 to 2100 Local. Then the crew reported for duty and flew for more than 8 hours through the night to DFW.

The first officer told investigators that he felt tired twice during the flight and briefly used oxygen to "perk-up." The captain and the flight engineer said they did not feel tired during the flight, but the literature on sleep indicates that people often fail to recognize when their performance deteriorates due to fatigue and disrupted circadian rhythms.

The second accident occurred on August 25, 1996, when a Lockheed L-1011-100 operated by Trans World Airlines was substantially damaged when the tail struck the runway while landing at John F. Kennedy International Airport. The accident occurred at 0710 EDT. None of the crew or passengers were injured. The NTSB determined the probable cause of the accident was pilot error.

Pilot fatigue was also a probable contributing factor in this accident. The crew's trip sequence began with an evening flight on August 23 from JFK to Las Vegas (LAS). The NTSB report is unclear about the time the crew arrived in LAS, but they appear to have reached their hotel around 2200 local time (0100 EDT), at which time the crew started a 24-hour rest period. The crew's itinerary resumed at 2130 (PDT) the next night when they were picked up at the hotel. The crew therefore would have been awake at least since about 2000 (2300 EDT). Though the crew had an ostensibly adequate rest period, they had arrived at their hotel late on the preceding night and were resuming their itinerary on the back side of the clock for a 5-hour red-eye to New York.

These two accidents resulted in two passengers who were seriously injured, and 38 crew members and a passenger who received minor injuries.

Late Night Duty Fatigue

Aviation accidents can also be examined how they vary through out the day. As can be seen in Table 3 showing the 43 accidents in our analysis by time of day, accidents are more likely to occur in the late afternoon and early evening (4:00 pm to 8:00 pm) than any other time of the day. During the rest of the day accidents are spread out fairly evenly among the four-hour categories. Throughout most of the day there is a close relationship between the percentage of accidents that occurred during each four-hour period and the percentage of operations that occurred during the same four-hour period. However, between midnight and 4:00 AM, the percentage of accidents (14%) greatly exceed the percentage of operations (3%).

Table 3 Accidents by Time of Day

Time Period	Number of Human Factors Accidents	Percentage of Human Factors Accidents	Number of Operations	Percentage of Operations
mid to 4	6	14.0%	708,610	3.0%
4 to 8	6	14.0%	2,535,742	10.8%
8 to noon	7	16.3%	5,383,139	22.8%
noon to 4pm	6	14.0%	5,557,144	23.6%
4 to 8pm	11	25.6%	5,746,663	24.4%
8 to mid	7	16.3%	3,649,924	15.5%
	43		23,581,222	

This analysis is also consistent with a study of pilot deviations by time-of-day (see Appendix C). In this study the portion of pilot deviations was greater than the exposure portion between midnight and 4:00 am. Both this study and the above analysis suggest that should be regulated to reduce the number of pilot error accidents where pilot fatigue was a contributing factor.

It is possible to estimate the number of accidents that could have been avoided by regulating operations during the window of circadian low between 12:00 midnight and 4:00 am using the information in Table 3. If fatigue was not a contributing factor in the 13 accidents that occurred between 8:00 am and 4:00 pm, then the relationship between the exposure data compiled for captains and the "normal" frequency of occurrence of serious accidents can be estimated as 1.19 accidents per million operations. There were 708,610 operations between midnight and 4:00 am; and based on the calculated frequency relationship (1.19 accidents per million operations) 0.8 accidents would be expected to occur, and six accidents occurred during those hours. Between 4:00 am and 8:00 am there were 2.536 million operations. The expected number of accidents at the above rate would be 3.0 accidents during those hours, but there were six accidents. The excess accidents that occur in the late afternoon and evening have already been taken into account the earlier discussion in the sections preceding this section.

Table 4 shows the projected number of accidents estimated in this way in comparison with the actual number of accidents. The difference between the actual number of accidents and the projected number of accidents would be the number of accidents that may be avoided by regulating operations during those hours. For example, between midnight and 4:00 am, there were six accidents,[12] and 0.8 were projected to

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[12] Cleveland, OH (2/17/1991), Swanton, OH (2/15/1992), East Garnby, CT (11/12/1995), Newark, NJ (7/31/1997), Florence, KY (8/13/2004) and Traverse City (4/12/2007).

occur; so there is a difference of 5.2 accidents. Similarly, between 4:00 am and 8:00 am, there were six accidents,[13] while 3.0 were projected to occur; the difference (or possible number of accidents avoided) is 2.98 accidents.

Table 4

Hour of Day	Accidents	Projected Accidents	Difference
mid to 4	6	0.8	5.2
4 to 8	6	3.0	3.0
8 to noon	7	6.4	
noon to 4pm	6	6.6	
4 to 8pm	11	6.8	
8 to mid	7	4.3	
	43		

A rule that regulated operations during the period of circadian low between midnight and 4:00 am could avoid 5.2 accidents. If the time was extended to 6:00 am, then possibly 3.0 accidents could be avoided. As it turns out, one of the accidents that occurred between midnight and 4:00 am, Traverse City (4/12/2007), has already been accounted for in the above analysis of length of duty time accidents, so it will not be claimed in this analysis. Concerning the time between 4:00 am and 8:00 am, only one of the six accidents occurred when the window of circadian low was possible (between 4:00 am and 6:00 am). That accident happened at Tallahassee (7/26/2002), and it also was discussed above. None of the accidents between 4:00 am and 8:00 am will be claimed in this analysis.

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[13] Dallas/Ft Worth (4/14/1993), Nashville, TN (7/08/1996), Jamaica, NY (8/25/1996), Jamaica, NY (5/8/1999), Tallahassee, FL (7/26/2002), and Lexington, KY (8/27/2006) .

Operating an aircraft during the window of circadian low can be fatiguing. The five accidents described below all occurred between midnight and 6:00 am. These five accidents resulted in seven fatalities. There were also 7 minor injuries passengers and crew members, and 77 crew members and a passenger that received minor injuries.

The first accident occurred on February 17, 1991, when a McDonnell Douglas DC-9-15 freighter operated by Ryan International Airlines flew through weather conducive to airframe ice contaminations 40 minutes prior to descending toward Cleveland, OH. During the 35 minute turnaround at Cleveland, the crew did not exit the airplane to conduct a preflight inspection of the airplane even though it was snowing at the time. The airplane stalled on the takeoff and crashed. The accident happened at 00:19 EST. Both flight crewmembers were fatally injured. The NTSB determined that pilot error was the probable cause of the accident.

The second accident occurred February 15, 1992, when a Douglas DC-8-63 operated by Air Transport International crashed on approach to the airport at Toledo, OH. The first officer had attempted two ILS approaches but failed to capture the ILS localizer and/or glideslope. During the second approach the captain assumed control of the airplane. The captain apparently became spatially disoriented and failed to properly recognize and recover from an unusual aircraft attitude. The second officer assumed control of the aircraft but was unable to recover the airplane before it crashed. The accident occurred at 3:27 EST. The captain, first officer, and two other people were fatally injured. The NTSB determined that pilot error was the probable cause of the accident.

The third accident occurred on November 12, 1995, when a McDonnell Douglas MD-83 operated by American Airlines, Inc. struck some trees and then an ILS antenna as it landed short of the runway on approach to Bradley International Airport, Windsor Locks, CT. The accident happened at 00:57 EST. Only one passenger received minor injuries. The other 77 passengers and crew members were uninjured. The NTSB determined that pilot error was the probable cause of the accident.

The fourth accident occurred on July 31, 1997, when McDonnell Douglas MD-11 operated by Federal Express, Inc. made a hard landing at Newark International Airport, Newark, NJ. The airplane bounced and made another hard landing. When the airplane came to a stop, a fire broke out and destroyed the airplane. The accident occurred 01:30 EDT. The two flight crewmembers and three company personnel received minor injuries. The NTSB determined that pilot error was the probable cause of the accident.

The fifth accident occurred on August 13, 2004, when a Convair 580 crashed on approach to Cincinnati/Northern Kentucky International Airport, Covington, KY. The accident happened at 00:49 EDT. The accident was the result of fuel starvation because the flight crew did follow approved procedures. The first office received fatal injuries while the captain received minor injuries. The airplane was destroyed by the impact. The NTSB determined that pilot error was the probable cause of the accident.

These five accidents resulted in seven fatalities. There were also 7 minor injuries passengers and crew members, and 77 crew members and a passenger that received minor injuries.

Summary of Above Analyses

Pilot fatigue is a serious problem. If nothing is done about this problem, we can expect about one aviation accident a year (possibly over six accidents) where pilot fatigue will be a contributing factor. Pilot fatigue will be a contributing factor in many accidents that could potentially cost billions of dollars.

During the past 20 years, there have been over 18 aviation accidents caused by pilot error where pilot fatigue was a factor. NTSB has identified five accidents where the flight crew started the day in a state of fatigue. We statistically identified 4.6 accidents where the flight crew became fatigued during a long flight-duty period (NTSB cited pilot fatigue as a contributing factor in three of those accidents). We have also statistically estimated that some of the 6.2 accidents that occurred between midnight and 6:00 am involved pilot fatigue. Two of these have already been accounted for in the previously discussed analyses. There were also three accidents where the pilot became fatigued due to being awake for many hours. Lastly, there were two accidents were chronic fatigue was a contributing factor. In summary, we project there would be at least 18.8 accidents (13 passenger airplane accidents and 5.8 cargo airplane accidents) during the next 20 years where pilot fatigue would be a contributing factor to the accident.

Simulation Results

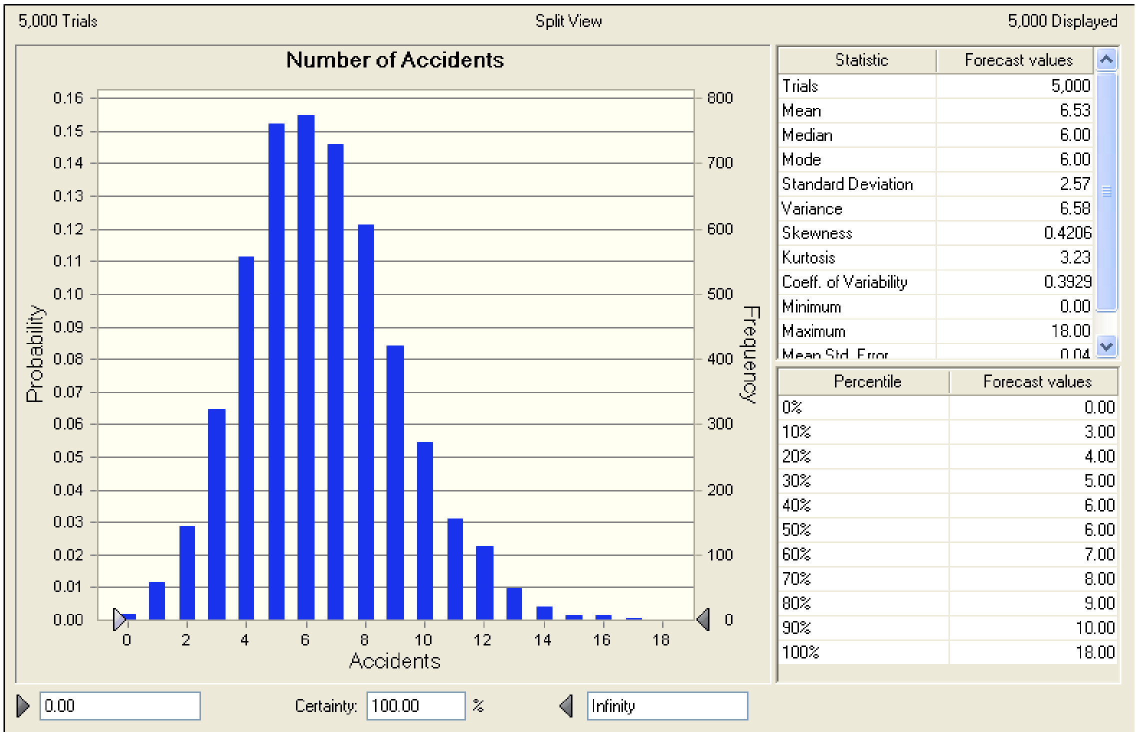
Simulation is a tool that we can use to study how many future accidents might occur and how severe these future accidents might be. The passenger and crew casualties in the simulated accidents will be different from those in the past. The casualty estimates are based on 278 aviation accidents that occurred during the past 20 years because of pilot error. The exact pilot error that will cause these future accidents could be any one of the pilot errors that have occurred during the past 20 years, and need not be the same as those errors that caused the above 18.8 accidents. The aircraft in the simulated future accidents could also be different from those in the above accidents.

Lower Estimated Results

Projected Passenger Airplane Accidents

From the above analysis, 13 passenger airplane accidents are expected to occur every 20 years, or 0.65 accidents a year. A 5,000 trial simulation analysis was run with a mean value of 0.65 to provide a distribution of the possible outcomes over any future 10-year period. The median was 6 accidents; the mean was 6.5 accidents; and the range was from no accidents to 18 accidents.

Figure 1.Distribution of Possible Future Passenger Airplane Accidents



5,000 Trials Split View 5,000 Displayed

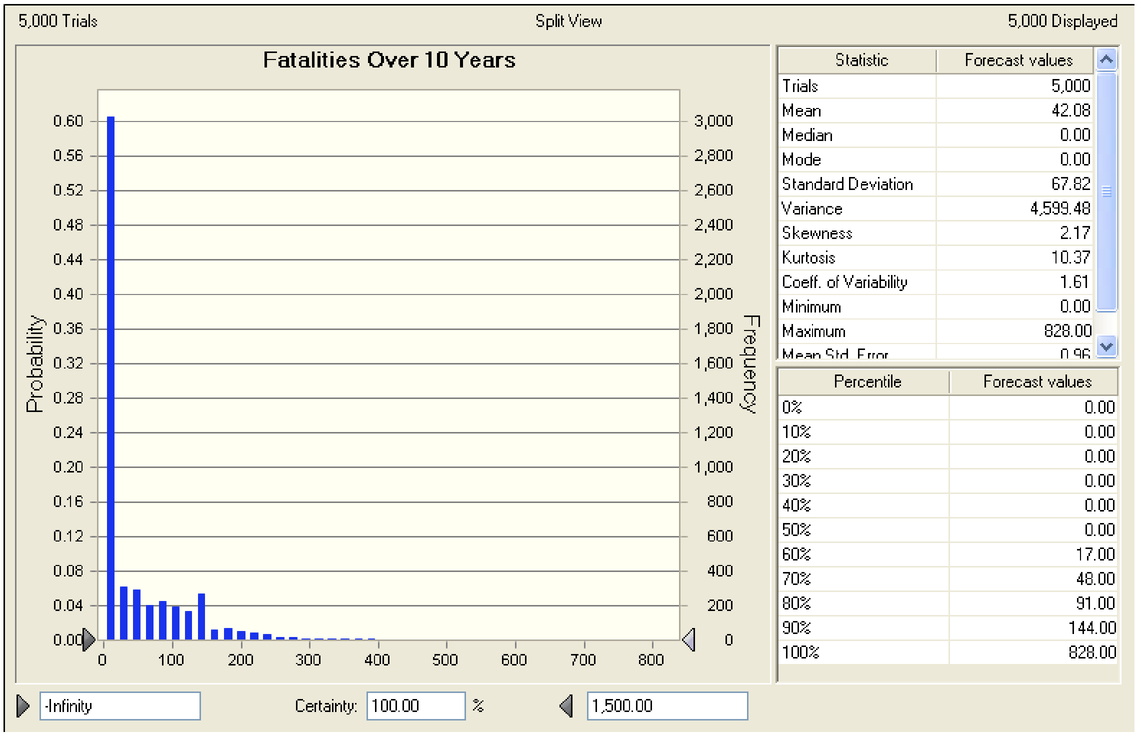
Statistic	Forecast values
Trials	5,000
Mean	6.53
Median	6.00
Mode	6.00
Standard Deviation	2.57
Variance	6.58
Skewness	0.4206
Kurtosis	3.23
Coeff. of Variability	0.3929
Minimum	0.00
Maximum	18.00
Mean Std. Error	0.04

Percentile	Forecast values
0%	0.00
10%	3.00
20%	4.00
30%	5.00
40%	6.00
50%	6.00
60%	7.00
70%	8.00
80%	9.00
90%	10.00
100%	18.00

0.00 Certainty: 100.00 % Infinity

On the other hand, the distribution of future fatalities is not a normal distribution, but is skewed to the right (see figure 2). For at least 50 percent of the simulation trials there were no fatalities during any 10-year period. This is not surprising, since in over 90 percent of the accidents used to develop the simulation model, there were no fatalities. However, the right tail of this distribution is long and heavy. There could be as many as 828 fatalities during a future 10-year period – a catastrophic collision involving two fully loaded wide-body airplanes and one other catastrophic accident also involving a fully loaded wide-body airplane could produce this number of fatalities. The mean of the simulation distribution of possible future fatalities was 42. The simulation results suggest there is a 30 percent chance there could be 48 or more fatalities during a future 10-year period, a 20 percent chance there could be 91 or more fatalities, and a 10 percent chance there could be 144 or more fatalities.

Figure 2. Distribution of Possible Future Fatalities



5,000 Trials Split View 5,000 Displayed

Statistic	Forecast values
Trials	5,000
Mean	42.08
Median	0.00
Mode	0.00
Standard Deviation	67.82
Variance	4,599.48
Skewness	2.17
Kurtosis	10.37
Coeff. of Variability	1.61
Minimum	0.00
Maximum	828.00
Mean Std. Error	0.96

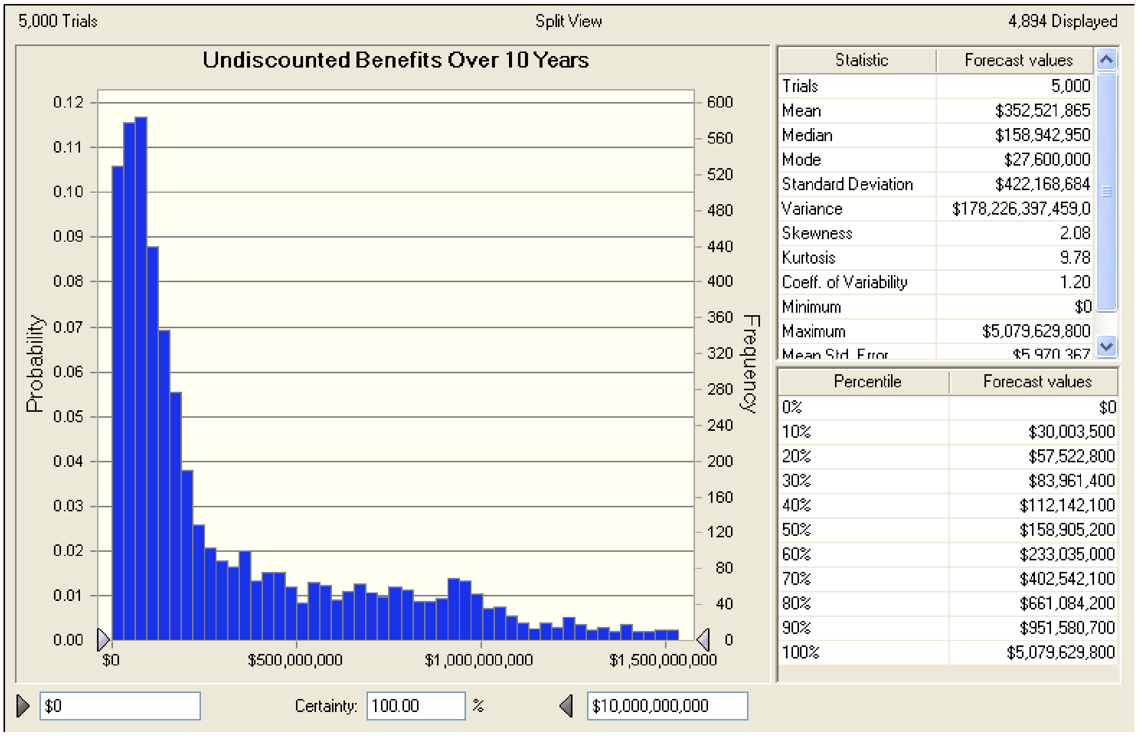
Percentile	Forecast values
0%	0.00
10%	0.00
20%	0.00
30%	0.00
40%	0.00
50%	0.00
60%	17.00
70%	48.00
80%	91.00
90%	144.00
100%	828.00

-Infinity Certainty: 100.00 % 1,500.00

The distribution of the undiscounted costs of the possible future passenger airplane accidents is shown in figure 3. The distribution of the costs, like the distribution for possible future fatalities, is heavily skewed to the right. The median for the costs is \$158.9 million, while the mean is \$352.5 million. The minimum cost is zero and the maximum cost is \$5.080 billion. There is a 30 percent chance that costs would exceed

$402 million; there is a 20 percent chance that costs would exceed $661 million; and a 10 percent chance that costs would exceed $951 million.

Figure 3 Distribution of Benefits of Avoiding Possible Future Passenger Airplane Accidents



Statistic	Forecast values
Trials	5,000
Mean	$352,521,865
Median	$158,942,950
Mode	$27,600,000
Standard Deviation	$422,168,684
Variance	$178,226,397,459,0
Skewness	2.08
Kurtosis	9.78
Coeff. of Variability	1.20
Minimum	$0
Maximum	$5,079,629,800
Mean Std. Error	$5,970,367

Percentile	Forecast values
0%	$0
10%	$30,003,500
20%	$57,522,800
30%	$83,961,400
40%	$112,142,100
50%	$158,905,200
60%	$233,035,000
70%	$402,542,100
80%	$661,084,200
90%	$951,580,700
100%	$5,079,629,800

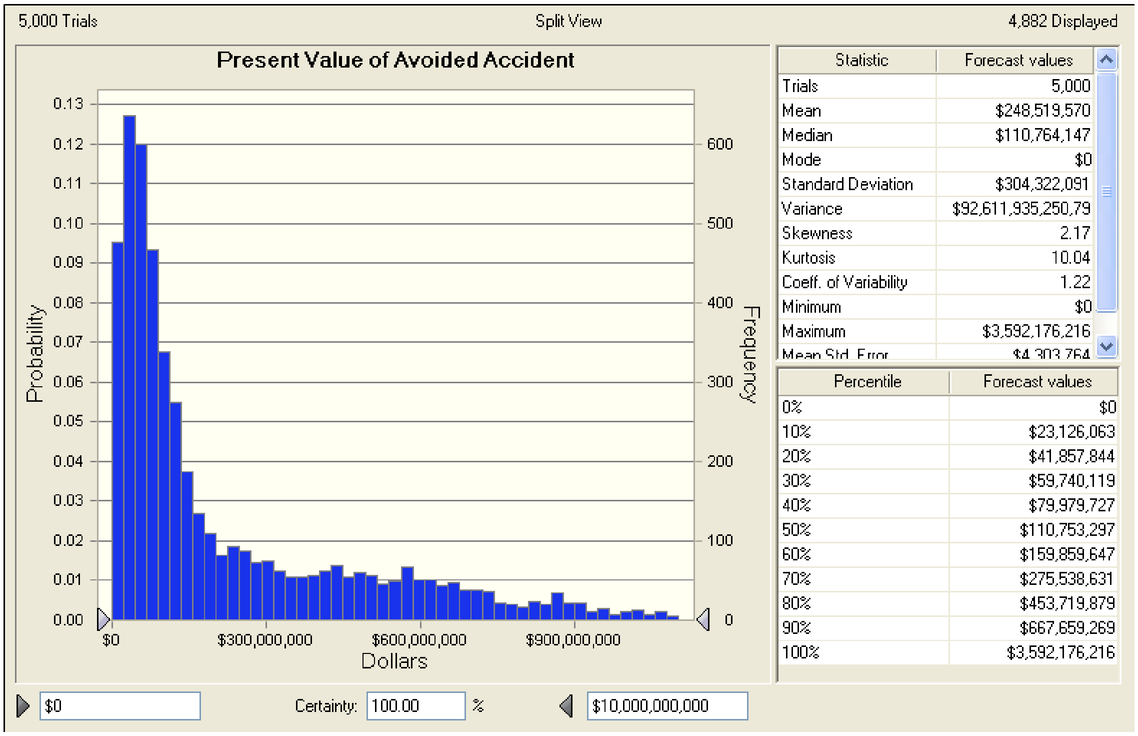
$0

Certainty: 100.00 %

$10,000,000,000

Figure 4 shows the distribution of the present value of the possible future accidents. It is similar to figure 3 though the values are a little lower. The median value is $110.8 million; mean value is $248.5 million; and the maximum value is $3.592 billion.

Figure 4 Distribution of the Present Value of the Costs of Possible Future Passenger Airplane Accidents



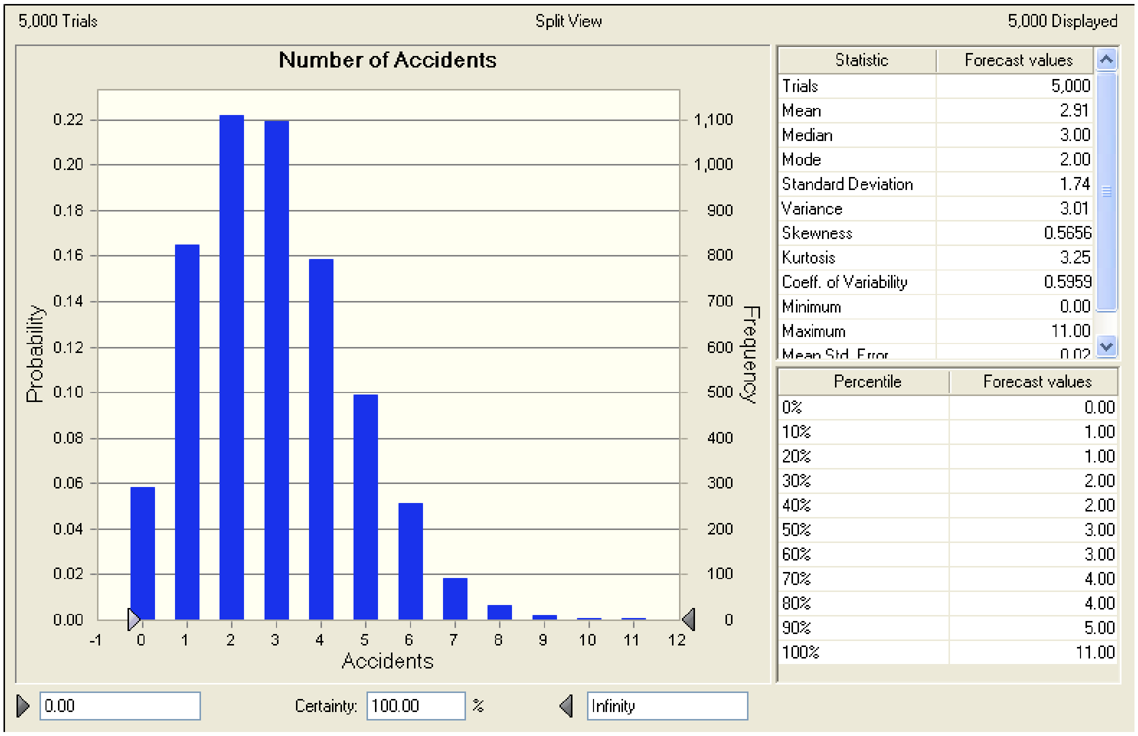
Statistic	Forecast values
Trials	5,000
Mean	$248,519,570
Median	$110,764,147
Mode	$0
Standard Deviation	$304,322,091
Variance	$92,611,935,250,79
Skewness	2.17
Kurtosis	10.04
Coeff. of Variability	1.22
Minimum	$0
Maximum	$3,592,176,216
Mean Std. Error	$4,303,764

Percentile	Forecast values
0%	$0
10%	$23,126,063
20%	$41,857,844
30%	$59,740,119
40%	$79,979,727
50%	$110,753,297
60%	$159,859,647
70%	$275,538,631
80%	$453,719,879
90%	$667,659,269
100%	$3,592,176,216

Projected Cargo Airplane Accidents

Based on the accident analysis above, 5.8 cargo airplane accidents are expected to occur every 10 years, or 0.29 accidents a year. A 5,000 trial simulation analysis using a Poisson distribution with a mean value of 0.29 was run to provide a distribution of the possible outcomes over any future 10-year period. In this case, the distribution of possible future number of passenger airplane accidents during any 10-year period (see figure 5) had almost a normal distribution, though slightly skewed to the right. The median is 3 accidents; the mean was 2.9 accidents; and the range was from no accidents to 11 accidents.

Figure 5 Distribution of Possible Future Cargo Airplane Accidents



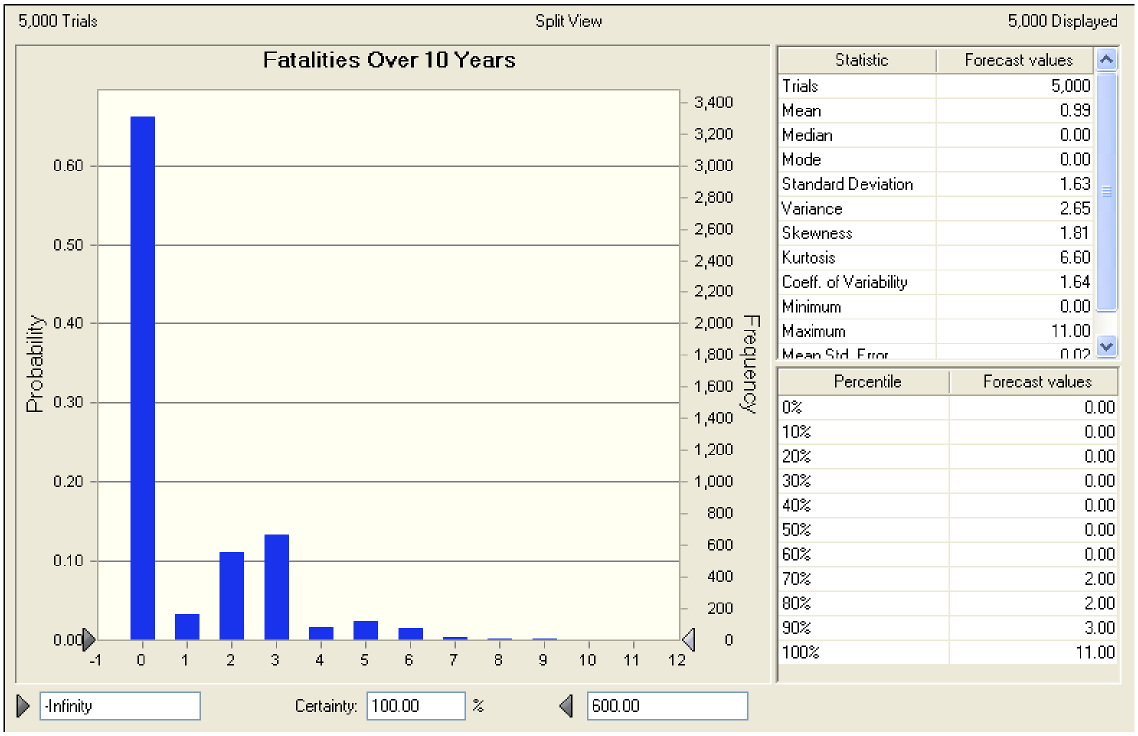
Statistic	Forecast values
Trials	5,000
Mean	2.91
Median	3.00
Mode	2.00
Standard Deviation	1.74
Variance	3.01
Skewness	0.5656
Kurtosis	3.25
Coeff. of Variability	0.5959
Minimum	0.00
Maximum	11.00
Mean Std. Error	0.02

Percentile	Forecast values
0%	0.00
10%	1.00
20%	1.00
30%	2.00
40%	2.00
50%	3.00
60%	3.00
70%	4.00
80%	4.00
90%	5.00
100%	11.00

0.00 Certainty: 100.00 % Infinity

Figure 6 shows the distribution of fatalities for possible future cargo accidents. This simulation run projects few fatalities in cargo airplane accidents than for passenger airplane accidents. Over 60 percent of the simulation trials result in no fatalities during any 10-year period. Under 40 percent of the trail result in fatalities. The mean for this distribution is one fatality during a 10-year period. There could be as many as 11 fatalities during a future 10-year period. The simulation results suggest there is a 30 percent chance there could be 2 or more fatalities during a future 10-year period, and a 20 percent chance there could be 3 or more fatalities.

Figure 6 Distribution of Fatalities from Possible Future Cargo Airplane Accidents



Statistic	Forecast values
Trials	5,000
Mean	0.99
Median	0.00
Mode	0.00
Standard Deviation	1.63
Variance	2.65
Skewness	1.81
Kurtosis	6.60
Coeff. of Variability	1.64
Minimum	0.00
Maximum	11.00
Mean Std. Error	0.02

Percentile	Forecast values
0%	0.00
10%	0.00
20%	0.00
30%	0.00
40%	0.00
50%	0.00
60%	0.00
70%	2.00
80%	2.00
90%	3.00
100%	11.00

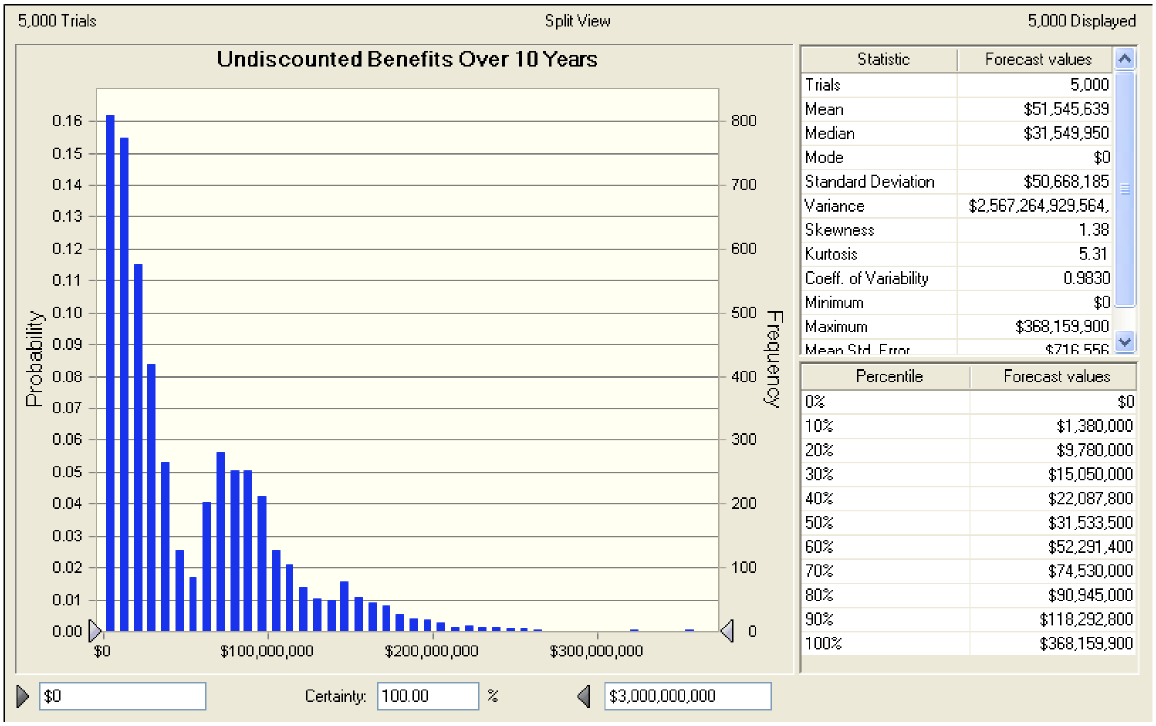
-Infinity

Certainty: 100.00 %

600.00

The undiscounted costs of these simulated future cargo accidents are shown in Figure 7. Since there few casualties, most of the cost will be the result damage to the airplane and to the cargo carried. The distribution of the costs is still skewed to the right. The median for the costs is $31.5 million, while the mean is $51.5 million. The minimum cost is zero and the maximum cost is $368.2 million. There is a 30 percent chance that costs would exceed $74 million; there is a 20 percent chance that costs would exceed $90 million; and a 10 percent chance that costs would exceed $118 million.

Figure 7 Distribution of the Undiscounted Benefits from Avoiding Possible Future Cargo Airplane Accidents



Statistic	Forecast values
Trials	5,000
Mean	$51,545,639
Median	$31,549,950
Mode	$0
Standard Deviation	$50,668,185
Variance	$2,567,264,929,564,
Skewness	1.38
Kurtosis	5.31
Coeff. of Variability	0.9830
Minimum	$0
Maximum	$368,159,900
Mean Std. Error	$716,556

Percentile	Forecast values
0%	$0
10%	$1,380,000
20%	$9,780,000
30%	$15,050,000
40%	$22,087,800
50%	$31,533,500
60%	$52,291,400
70%	$74,530,000
80%	$90,945,000
90%	$118,292,800
100%	$368,159,900

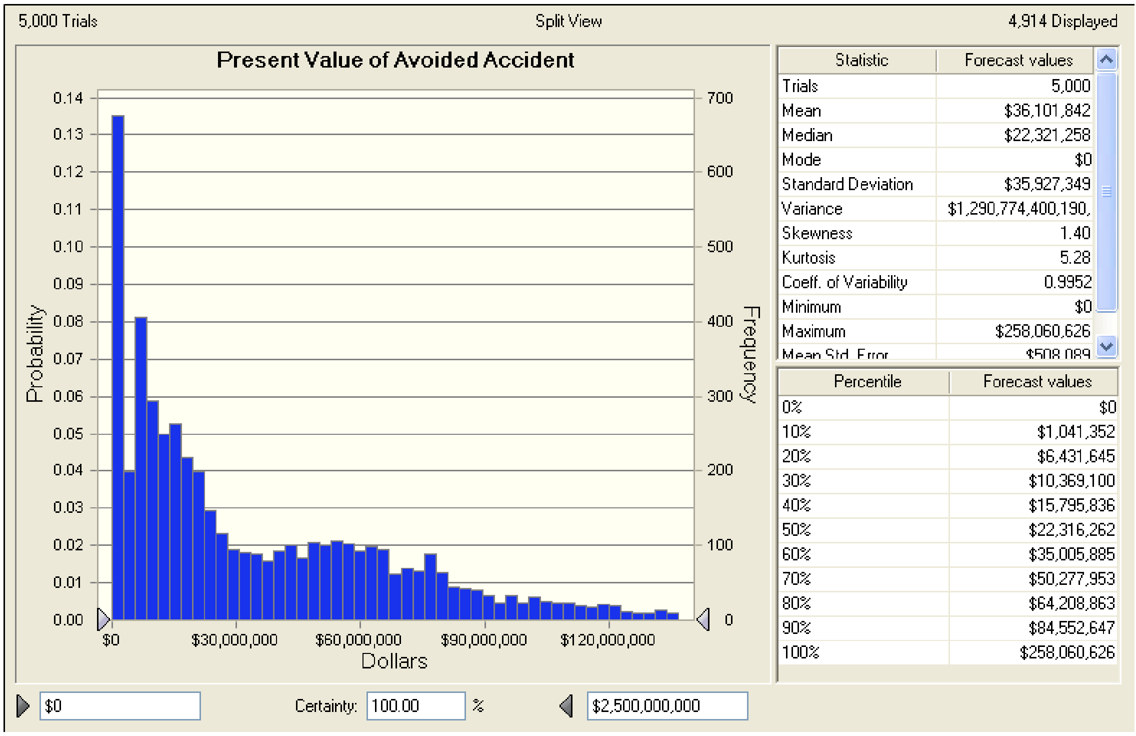
$0

Certainty: 100.00 %

$3,000,000,000

Figure 8 shows the distribution of the present value of the possible future accidents. It is similar to figure 7 though the values are a little lower. The median value is $22.3 million; mean value is $36.1 million; and the maximum value is $258.1 million.

Figure 8 Distribution of the Present Value of the Costs of Possible Future Cargo Accidents



Statistic	Forecast values
Trials	5,000
Mean	$36,101,842
Median	$22,321,258
Mode	$0
Standard Deviation	$35,927,349
Variance	$1,290,774,400,190,
Skewness	1.40
Kurtosis	5.28
Coeff. of Variability	0.9952
Minimum	$0
Maximum	$258,060,626
Mean Std. Error	$508,089

Percentile	Forecast values
0%	$0
10%	$1,041,352
20%	$6,431,645
30%	$10,369,100
40%	$15,795,836
50%	$22,316,262
60%	$35,005,885
70%	$50,277,953
80%	$64,208,863
90%	$84,552,647
100%	$258,060,626

$0

Certainty: 100.00 %

$2,500,000,000

Summary

If the simulation study is limited to just the number of possible accidents identified in the past 20-year period (which would be about 1.0 accidents per year), then there would be a mean of 9.4 airplane accidents in a 10-year period. These accidents would result in a mean of 43.1 deaths. The total estimated benefit from avoiding these simulated accidents has a mean value of $404.0 million ($284.6 million, present value).

Upper Estimate Results

Passenger Airplane Accidents

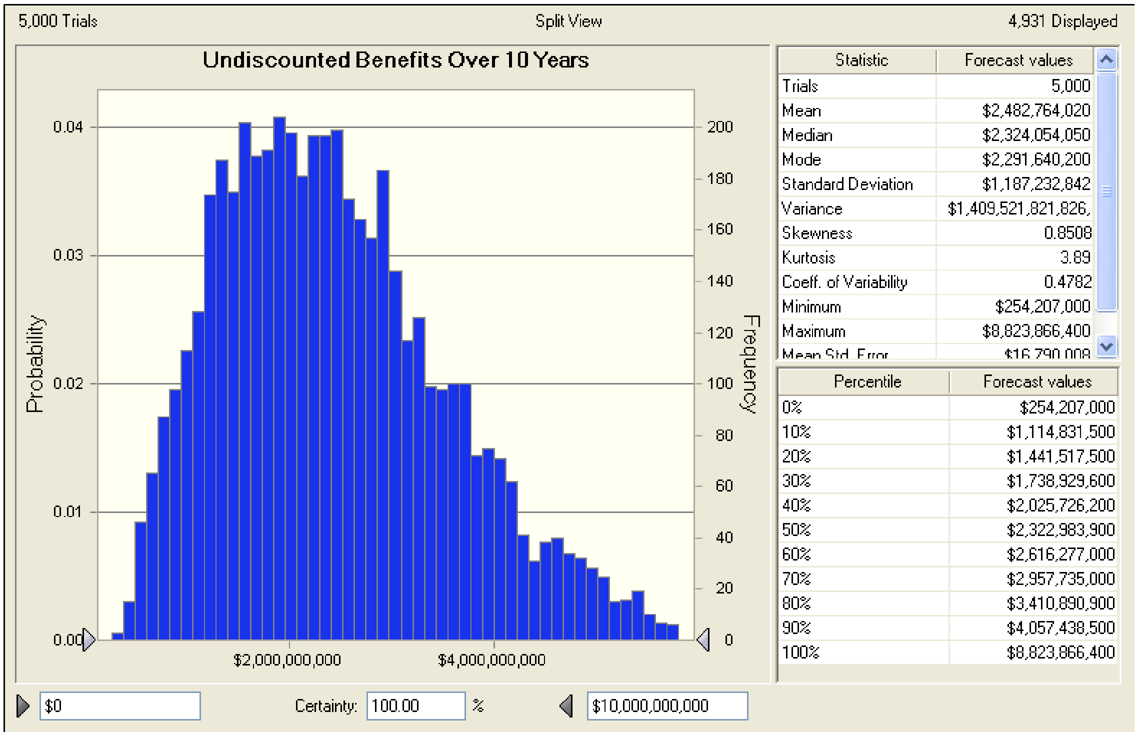
The passenger airplane accidents results above are based on the 33 passenger accidents where we have enough information in the accident report to make a judgment about the presence or absence of pilot fatigue. Pilot fatigue was present in 13 (or 39.4 percent) of those accidents. There are, however, 196 additional pilot error accidents involving passenger airplanes where that information is not available. If the same ratio (39.4 percent) of these 196 accidents were in part due to pilot fatigue, then there would be an additional 77.2 accidents where pilot fatigue was a contributing factor. Including the additional accidents would mean there could be over 90 passenger airplane accidents during the past 20 years where pilot fatigue would be a contributing factor. If the future is like the past, then the expected number of passenger airplane accidents would be 4.51 per year.

A 5,000 trial simulation analysis using a Poisson distribution with a mean value of 4.51 was run to provide a distribution of the possible outcomes of passenger airplane accidents over any future 10-year period. The distribution of possible future number of passenger airplane accidents during any 10-year period has almost a normal distribution. The mean is 45.15 accidents; and the standard deviation is 6.71 accidents. The range was from 22 accidents to 70 accidents.

Once again, the distribution of future fatalities is not a normal distribution, but is skewed to the right. This time, there are almost always some fatalities in each the simulation trial. There could be as many as 1,357 fatalities during a future 10-year period. The mean of the simulation distribution of possible future fatalities was 298. The simulation results suggest there is a 30 percent chance there could be 375 or more fatalities during a future 10-year period, a 20 percent chance there could be 448 or more fatalities, and a 10 percent chance there could be 551 or more fatalities.

The distribution of the undiscounted costs of the possible future passenger airplane accidents has a lognormal distribution (see figure 9). The median for the costs is $2.324 billion, while the mean is $2.483 billion. The minimum cost is $254.2 million and the maximum cost is $8.824 billion. There is a 30 percent chance that costs would exceed $2.957 billion; there is a 20 percent chance that costs would exceed $3.410 billion; and there is a 10 percent chance that costs would exceed $4.057 billion.

Figure 9 Distribution of Undiscounted Benefits of Avoiding Possible Future Passenger Airplane Accidents



Statistic	Forecast values
Trials	5,000
Mean	$2,482,764,020
Median	$2,324,054,050
Mode	$2,291,640,200
Standard Deviation	$1,187,232,842
Variance	$1,409,521,821,826,
Skewness	0.8508
Kurtosis	3.89
Coeff. of Variability	0.4782
Minimum	$254,207,000
Maximum	$8,823,866,400
Mean Std. Error	$16,790,008

Percentile	Forecast values
0%	$254,207,000
10%	$1,114,831,500
20%	$1,441,517,500
30%	$1,738,929,600
40%	$2,025,726,200
50%	$2,322,983,900
60%	$2,616,277,000
70%	$2,957,735,000
80%	$3,410,890,900
90%	$4,057,438,500
100%	$8,823,866,400

$0

Certainty: 100.00 %

$10,000,000,000

The distribution of the present value of the cost of the possible future accidents has a lognormal shape similar to that for undiscounted costs. However, the costs projections are a little lower. The mean value is $1.746 billion; and the maximum value is $6.839 billion. There is a 30 percent chance that costs would exceed $2.085 billion; there is a 20 percent chance that costs would exceed $2.406 billion; and a 10 percent chance that costs would exceed $2.875 billion.

Projected Cargo Airplane Accidents

The cargo airplane accidents results above are based on the 10 cargo airplane accidents where we have enough information in the accident report to make a judgment about the presence or absence of pilot fatigue. Pilot fatigue was present in 5.8 (or 58.0 percent) of those accidents. There are, however, 39 additional pilot error accidents involving passenger airplanes where that information is not available. If the same ratio (58.0 percent) of these 39 accidents were in part due to pilot fatigue, then there would be an additional 22.6 accidents where pilot fatigue was a contributing factor. Including the additional accidents would mean there could be over 28 cargo airplane accidents during the past 20 years where pilot fatigue would be a contributing factor. If the future is like the past, then the expected number of cargo airplane accidents would be 1.42 per year

A 5,000 trial simulation analysis using a Poisson distribution with a mean value of 1.42 was run to provide a distribution of the possible outcomes over any future 10-year period. The distribution of possible future number of cargo airplane accidents during any 10-year period had almost a normal distribution. The mean was 14.22 accidents; and the standard deviation is 3.83 accidents. The range is from three accidents to 31 accidents.

This simulation run projects more fatalities in cargo airplane accidents than was the previous case for cargo airplane accidents. This time over 80 percent of the trails resulted in fatalities. The mean for this distribution is 4.8 fatalities during a 10-year period. There could possibly be as many as 22 fatalities during a future 10-year period. The simulation results suggest there is a 30 percent chance there could be 6 or more fatalities during a future 10-year period, a 20 percent chance there could be 8 or more fatalities, and a 10 percent chance there could be 10 fatalities.

The distribution of undiscounted costs of these simulated future cargo accidents has a lognormal shape. Once again, most of the cost will be the result damage to the airplane and to the cargo carried due to the low number of casualties in cargo airplane accidents. The mean is $251.8 million. The minimum cost is $12.4 million and the maximum cost is $752.2 million. There is a 30 percent chance that costs would exceed $299 million; there is a 20 percent chance that costs would exceed $339 million; and a 10 percent chance that costs would exceed $398 million.

The distribution of the present value of the costs of the possible future accidents is similar to that for undiscounted costs, but the values are a little lower. The mean value is $176.6 million; and the maximum value is $533.4 million.

Summary

When the simulation study is expanded to include all the additional accidents, the expected number of accidents would be 59.4 airplane accidents in a ten-year period. These accidents would result in a mean of 303 deaths. The total estimated benefit from avoiding these simulated accidents has a mean value of $2.735 billion ($1.923 billion, present value).

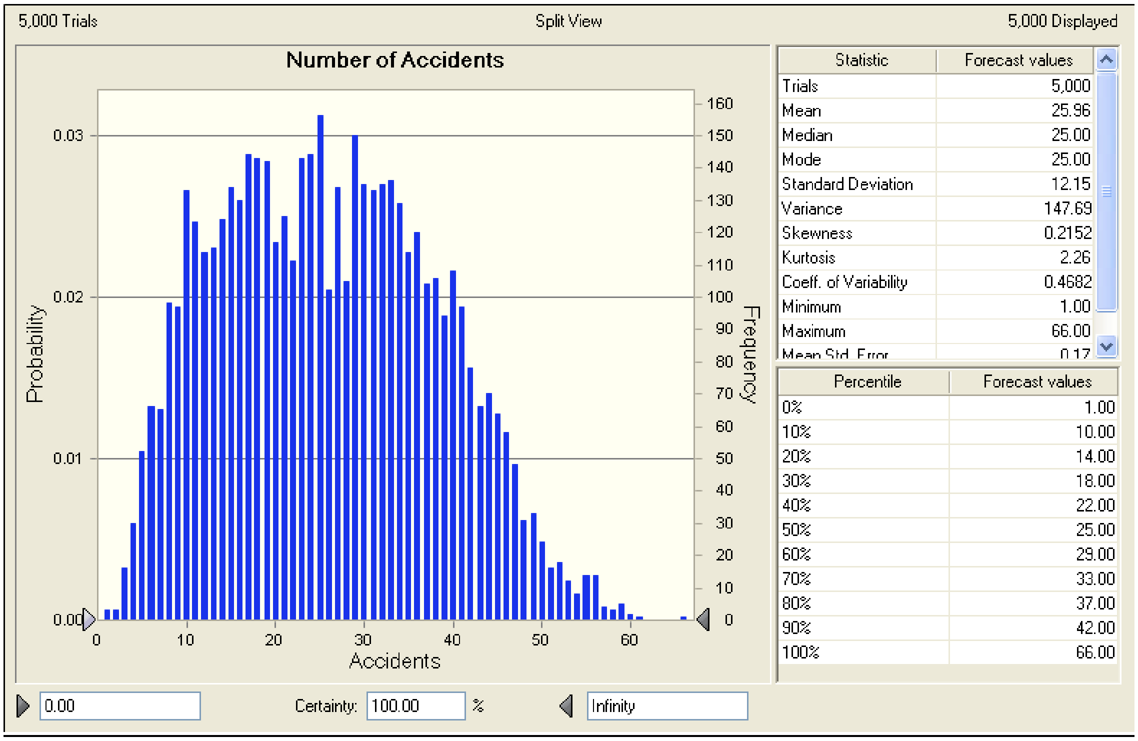
Best Estimate

The annual number of pilot fatigue related passenger airplane accidents is probably somewhere between 0.65 and 4.51, and the annual number of pilot related cargo airplane accidents is between 0.29 and 1.42. These ranges in the number of these types of accidents can also be addressed using simulation analysis.

Passenger Airplane Accidents

A 5,000 trial simulation analysis using a Poisson distribution with a mean ranging between 0.65 and 4.51 was run to provide a distribution of the possible outcomes of passenger airplane accidents over any future 10-year period (see figure 10). The mean is 25.96 accidents; and the standard deviation is 12.15 accidents. The range is between 1 and 66 accidents.

Figure 10 Distribution of Possible Future Passenger Airplane Accidents



Statistic	Forecast values
Trials	5,000
Mean	25.96
Median	25.00
Mode	25.00
Standard Deviation	12.15
Variance	147.69
Skewness	0.2152
Kurtosis	2.26
Coeff. of Variability	0.4682
Minimum	1.00
Maximum	66.00
Mean Std. Error	0.17

Percentile	Forecast values
0%	1.00
10%	10.00
20%	14.00
30%	18.00
40%	22.00
50%	25.00
60%	29.00
70%	33.00
80%	37.00
90%	42.00
100%	66.00

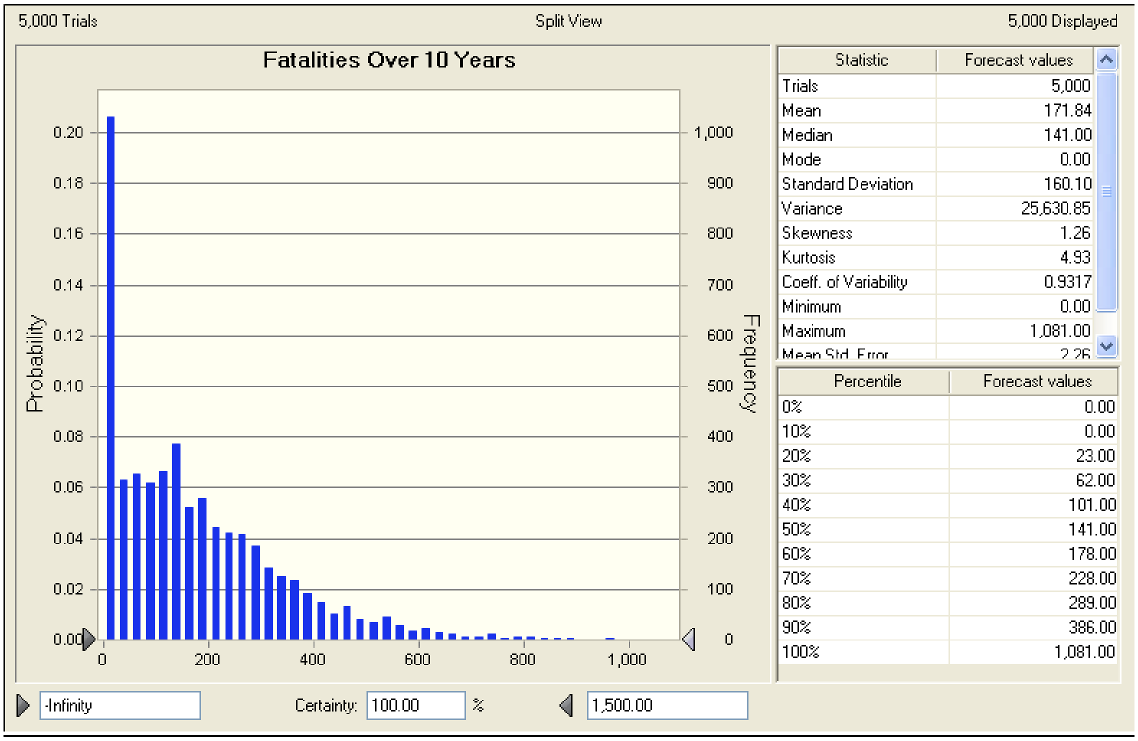
0.00

Certainty: 100.00 %

Infinity

The distribution of future fatalities is shown in figure 11. There is over an 80 percent chance there will be some fatalities during any given future 10-year period. There could possibly be as many as 1,081 fatalities during a future 10-year period. The mean of the simulation distribution of possible future fatalities was 172. The simulation results suggest there is a 30 percent chance there could be 228 or more fatalities during a future 10-year period, a 20 percent chance there could be 289 or more fatalities, and a 10 percent chance there could be 386 or more fatalities.

Figure 11 Distribution of Fatalities from Possible Future Passenger Airplane Accidents



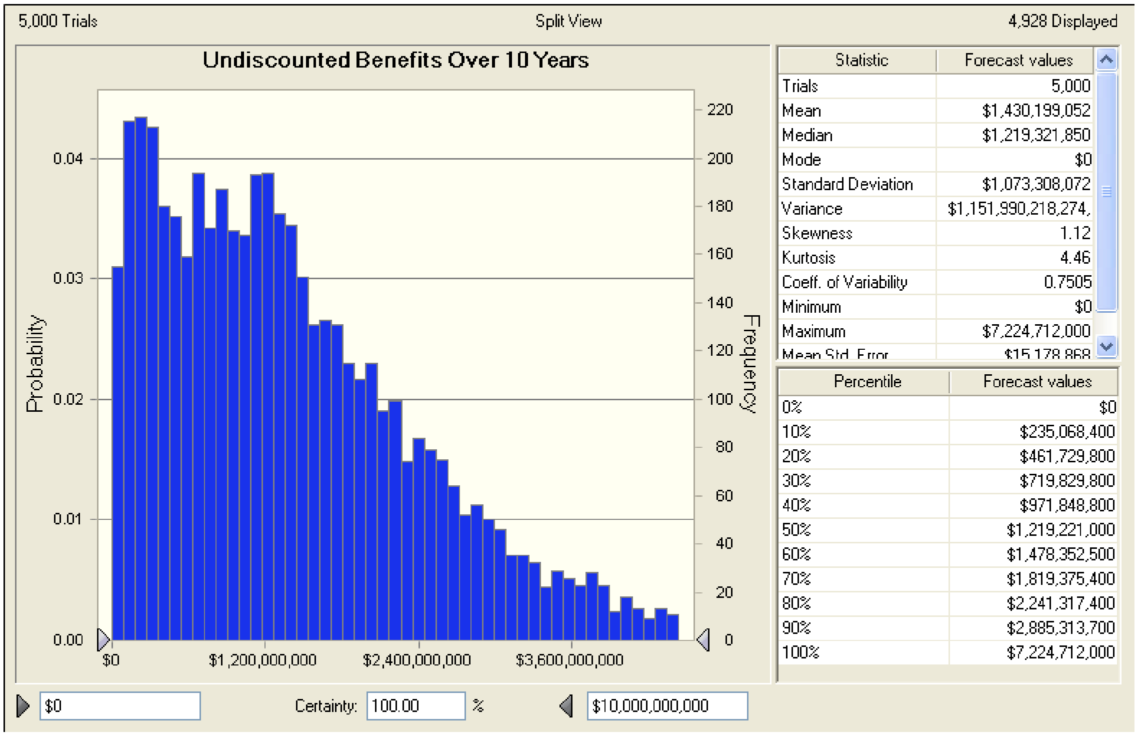
Statistic	Forecast values
Trials	5,000
Mean	171.84
Median	141.00
Mode	0.00
Standard Deviation	160.10
Variance	25,630.85
Skewness	1.26
Kurtosis	4.93
Coeff. of Variability	0.9317
Minimum	0.00
Maximum	1,081.00
Mean Std. Error	2.26

Percentile	Forecast values
0%	0.00
10%	0.00
20%	23.00
30%	62.00
40%	101.00
50%	141.00
60%	178.00
70%	228.00
80%	289.00
90%	386.00
100%	1,081.00

-Infinity Certainty: 100.00 % 1,500.00

The distribution of the undiscounted costs of the possible future passenger airplane accidents has a lognormal distribution (see figure 12). The median for the costs is $1.219 billion, while the mean is $1.430 billion. The minimum cost is zero and the maximum cost is $7.225 billion. There is a 30 percent chance that costs would exceed $1.819 billion; there is a 20 percent chance that costs would exceed $2.241 billion; and a 10 percent chance that costs would exceed $2.884 billion.

Figure 12 Distribution of Benefits of Avoiding Possible Future Passenger Airplane Accidents



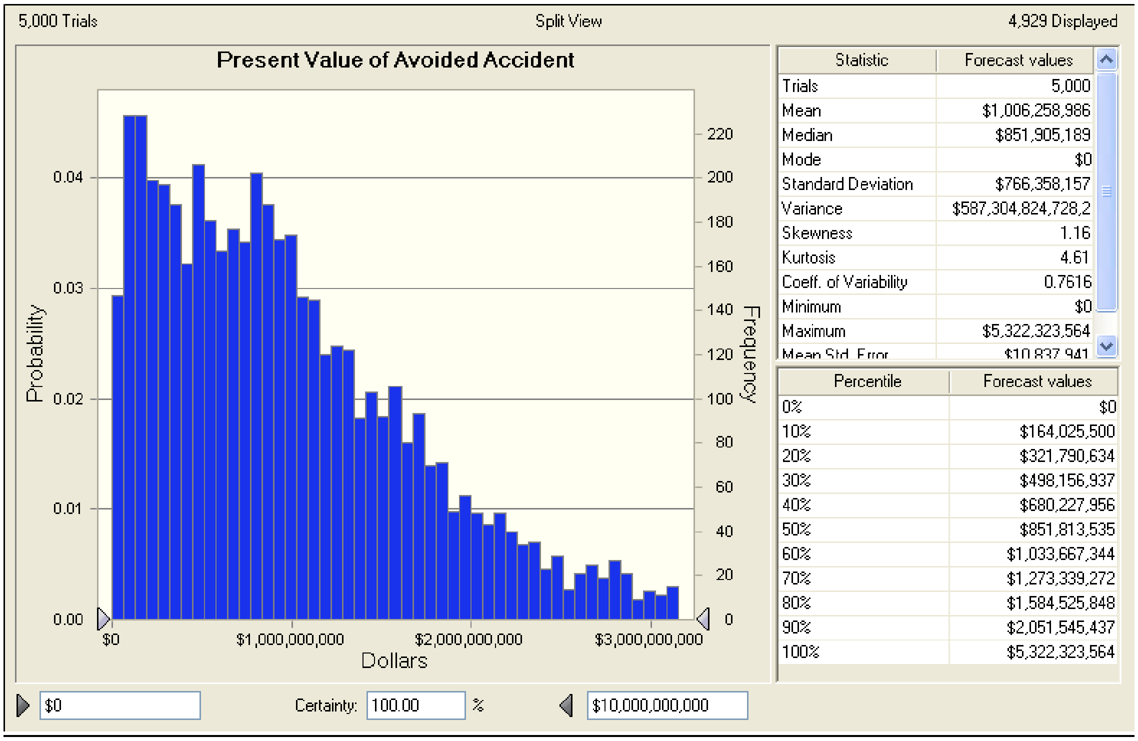
$0 — Certainty: 100.00 % — $10,000,000,000

Statistic	Forecast values
Trials	5,000
Mean	$1,430,199,052
Median	$1,219,321,850
Mode	$0
Standard Deviation	$1,073,308,072
Variance	$1,151,990,218,274,
Skewness	1.12
Kurtosis	4.46
Coeff. of Variability	0.7505
Minimum	$0
Maximum	$7,224,712,000
Mean Std. Error	$15,178,868

Percentile	Forecast values
0%	$0
10%	$235,068,400
20%	$461,729,800
30%	$719,829,800
40%	$971,848,800
50%	$1,219,221,000
60%	$1,478,352,500
70%	$1,819,375,400
80%	$2,241,317,400
90%	$2,885,313,700
100%	$7,224,712,000

The distribution of the present value of the cost of the possible future accidents has a lognormal shape similar to that for undiscounted costs, but the costs projections are a little lower. The mean value is $1.006 billion; and the maximum value is $5.322 billion. There is a 30 percent chance that costs would exceed $1.273 billion; there is a 20 percent chance that costs would exceed $1.584 billion; and a 10 percent chance that costs would exceed $2.051 billion.

Figure 13 Distribution of the Present Value of the Costs of Possible Future Passenger Airplane Accidents



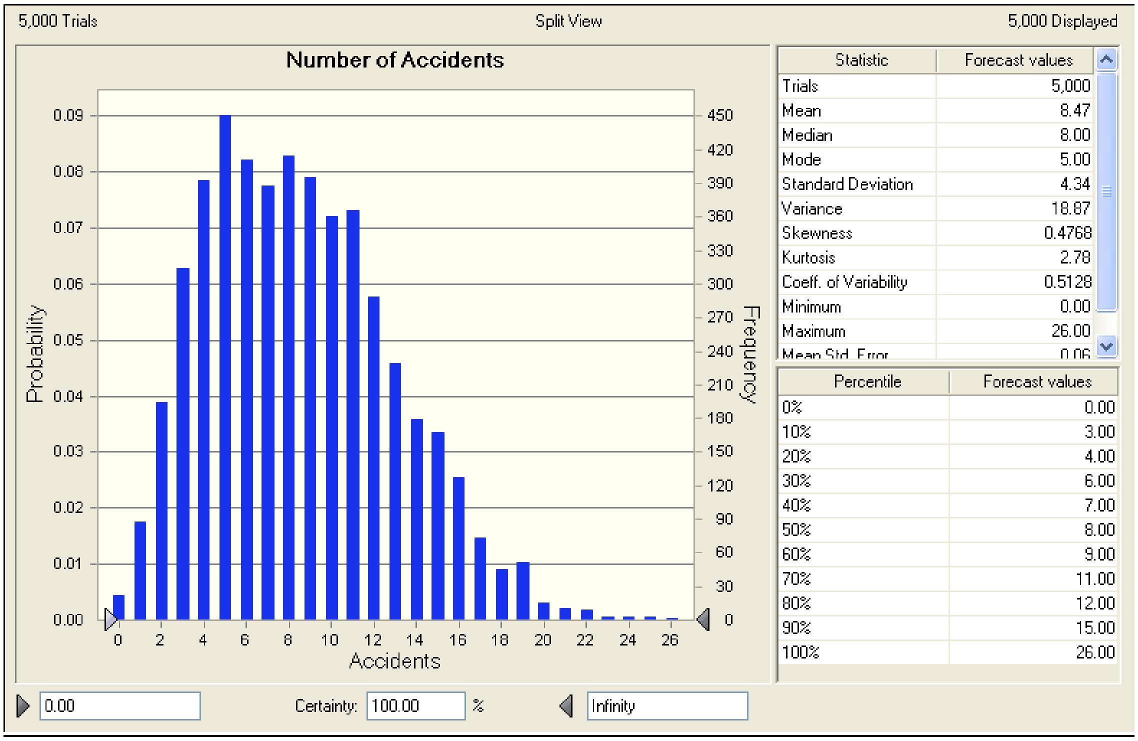
Statistic	Forecast values
Trials	5,000
Mean	$1,006,258,986
Median	$851,905,189
Mode	$0
Standard Deviation	$766,358,157
Variance	$587,304,824,728,2
Skewness	1.16
Kurtosis	4.61
Coeff. of Variability	0.7616
Minimum	$0
Maximum	$5,322,323,564
Mean Std. Error	$10,837,941

Percentile	Forecast values
0%	$0
10%	$164,025,500
20%	$321,790,634
30%	$498,156,937
40%	$680,227,956
50%	$851,813,535
60%	$1,033,667,344
70%	$1,273,339,272
80%	$1,584,525,848
90%	$2,051,545,437
100%	$5,322,323,564

Cargo Airplane Accidents

A 5,000 trial simulation analysis using a Poisson distribution with a mean ranging between 0.29 and 1.42 was run to provide a distribution of the possible outcomes of passenger airplane accidents over any future 10-year period (see figure 14). The mean is 8.47 accidents; and the standard deviation is 4.34 accidents. The range is between no accidents and 26 accidents.

Figure 14 Distribution of Possible Future Cargo Airplane Accidents



0.00

Certainty: 100.00 %

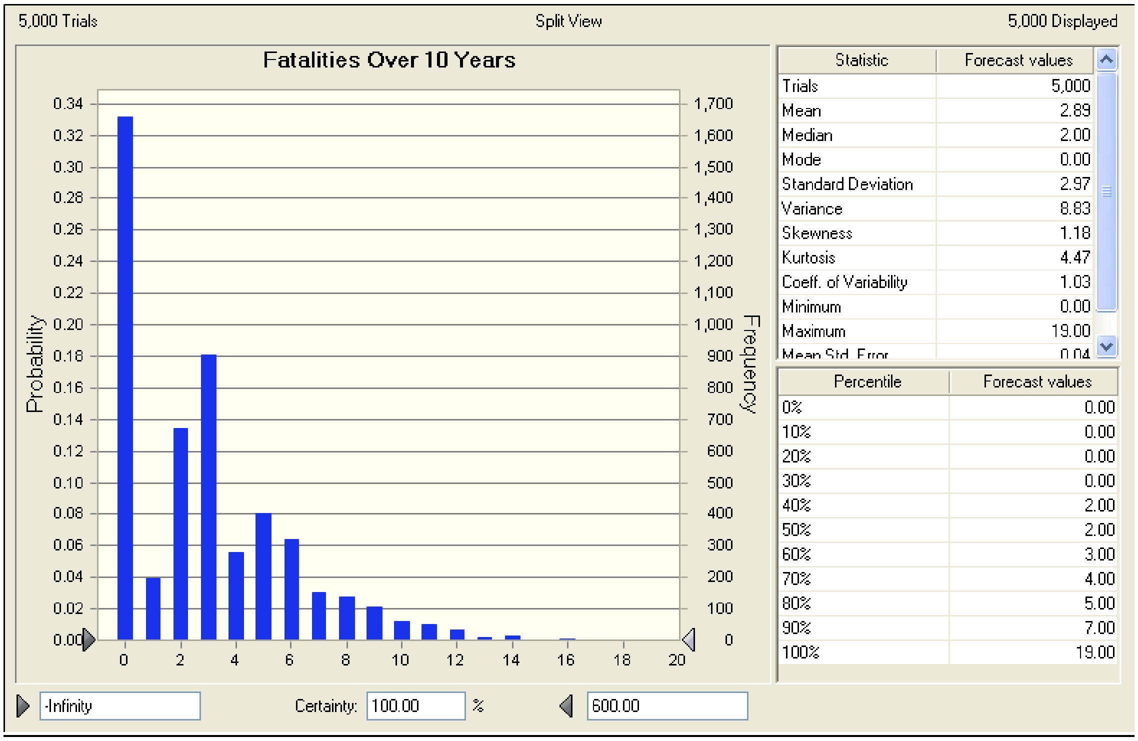
Infinity

Statistic	Forecast values
Trials	5,000
Mean	8.47
Median	8.00
Mode	5.00
Standard Deviation	4.34
Variance	18.87
Skewness	0.4768
Kurtosis	2.78
Coeff. of Variability	0.5128
Minimum	0.00
Maximum	26.00
Mean Std. Error	0.06

Percentile	Forecast values
0%	0.00
10%	3.00
20%	4.00
30%	6.00
40%	7.00
50%	8.00
60%	9.00
70%	11.00
80%	12.00
90%	15.00
100%	26.00

The distribution of future fatalities is shown in figure 15. There is over a 30 percent chance there will be no fatalities in each the simulation trial. However, there could possible be as many as 19 fatalities during a future 10-year period. The mean of the simulation distribution of possible future fatalities was 2.89. The simulation results suggest there is a 30 percent chance there could be 4 or more fatalities during a future 10-year period, a 20 percent chance there could be 5 or more fatalities, and a 10 percent chance there could be 7 or more fatalities.

Figure 15 Distribution of Fatalities from Possible Future Cargo Airplane Accidents



Statistic	Forecast values
Trials	5,000
Mean	2.89
Median	2.00
Mode	0.00
Standard Deviation	2.97
Variance	8.83
Skewness	1.18
Kurtosis	4.47
Coeff. of Variability	1.03
Minimum	0.00
Maximum	19.00
Mean Std. Error	0.04

Percentile	Forecast values
0%	0.00
10%	0.00
20%	0.00
30%	0.00
40%	2.00
50%	2.00
60%	3.00
70%	4.00
80%	5.00
90%	7.00
100%	19.00

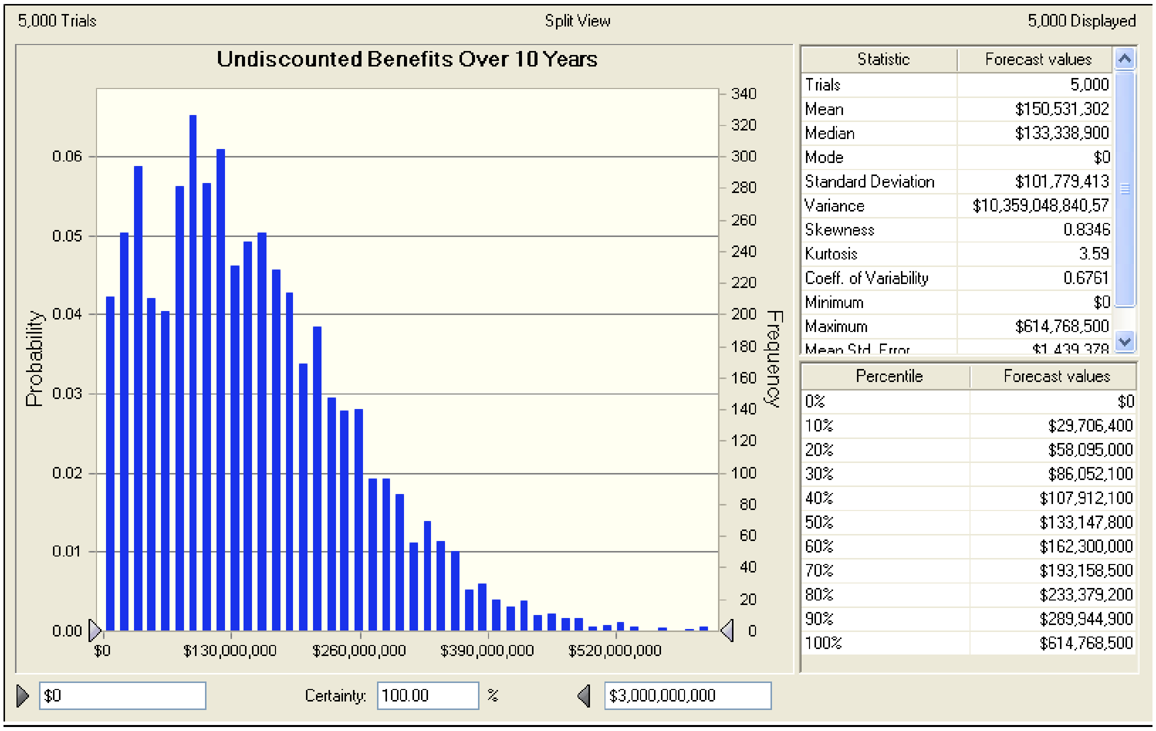
-Infinity

Certainty: 100.00 %

600.00

The distribution of the undiscounted costs of the possible future cargo airplane accidents is shown in figure 16. The median for the costs is $133.3 million, while the mean is $150.5 million. The minimum cost is zero and the maximum cost is $614.8 million. There is a 30 percent chance that costs would exceed $193 million; there is a 20 percent chance that costs would exceed $233 million; and a 10 percent chance that costs would exceed $289 million.

Figure 16 Distribution of Undiscounted Benefits of Avoiding Possible Future Cargo Accidents

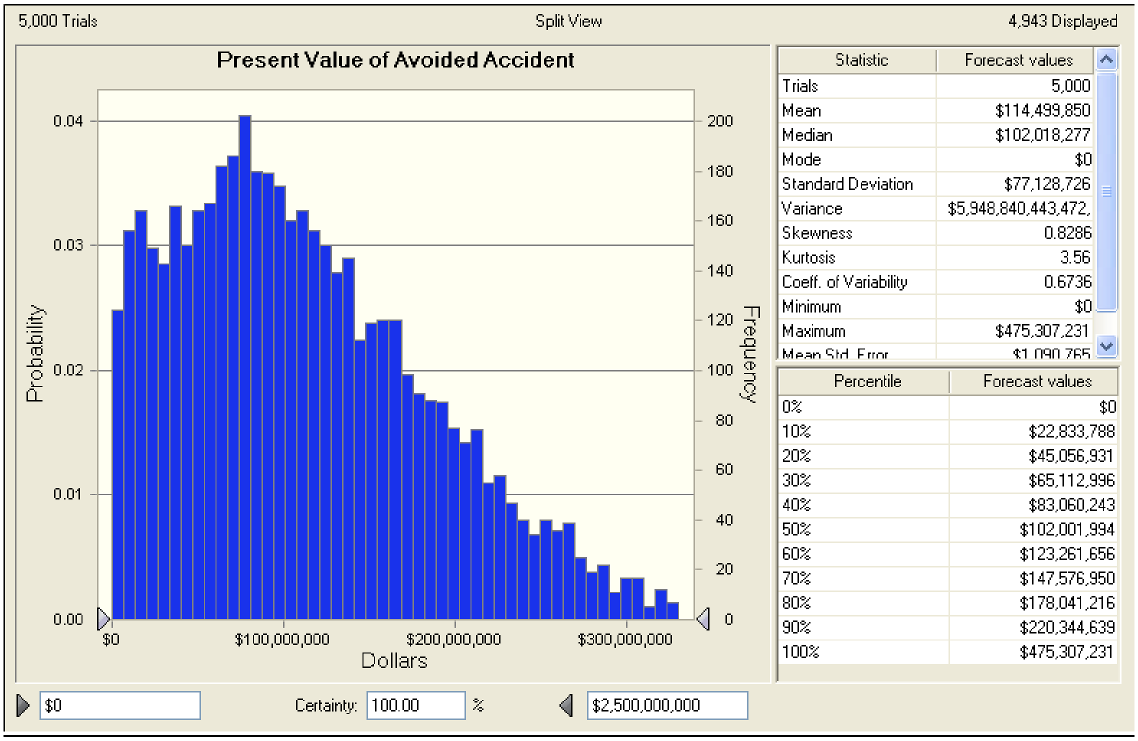


Statistic	Forecast values
Trials	5,000
Mean	$150,531,302
Median	$133,338,900
Mode	$0
Standard Deviation	$101,779,413
Variance	$10,359,048,840,57
Skewness	0.8346
Kurtosis	3.59
Coeff. of Variability	0.6761
Minimum	$0
Maximum	$614,768,500
Mean Std. Error	$1,439,378

Percentile	Forecast values
0%	$0
10%	$29,706,400
20%	$58,095,000
30%	$86,052,100
40%	$107,912,100
50%	$133,147,800
60%	$162,300,000
70%	$193,158,500
80%	$233,379,200
90%	$289,944,900
100%	$614,768,500

The distribution of the present value of the cost of the possible future accidents has a shape similar to that for undiscounted costs, but the costs projections are a little lower (see figure 17). The mean value is $114.5 million; and the maximum value is $475.3 million. There is a 30 percent chance that costs would exceed $147 million; there is a 20 percent chance that costs would exceed $178 million; and a 10 percent chance that costs would exceed $220 million.

Figure 17 Distribution of the Present Value of the Costs of Possible Future Cargo Airplane Accidents



5,000 Trials

Split View

4,943 Displayed

Statistic	Forecast values
Trials	5,000
Mean	$114,499,850
Median	$102,018,277
Mode	$0
Standard Deviation	$77,128,726
Variance	$5,948,840,443,472,
Skewness	0.8286
Kurtosis	3.56
Coeff. of Variability	0.6736
Minimum	$0
Maximum	$475,307,231
Mean Std. Error	$1,090,765

Percentile	Forecast values
0%	$0
10%	$22,833,788
20%	$45,056,931
30%	$65,112,996
40%	$83,060,243
50%	$102,001,994
60%	$123,261,656
70%	$147,576,950
80%	$178,041,216
90%	$220,344,639
100%	$475,307,231

$0

Certainty: 100.00 %

$2,500,000,000

Summary

When a range in the number of annual accidents is allowed in the simulation analysis, the mean is 28.9 airplane accidents in a ten-year period. These accidents would result in a mean of 174.7 deaths. The estimated cost of these accidents would be a mean value of $1.581 billion ($1.121 billion, present value). These numbers represent an estimate of the likely number of future accidents, deaths, and costs from future accidents with fatigue as a factor.

Effectiveness Analysis

The above analysis establishes an estimate of the number and range of fatigue related accidents if no action is taken to address the problem. It is seldom the case that a rule is 100 percent effective at addressing an identified problem. In particular, fatigue is rarely a primary or sole cause of an accident, and therefore this rule, if adopted, is not likely to prevent all future accidents that include fatigue as a factor.

FAA reviewed all NTSB accident reports on Part 121 accidents that occurred from 1990 through 2009 to assess the likely capacity of the NPRM to have averted those accidents. The dataset also included some Part 135 accidents prior to spring 1997 that occurred on flights which would have been subject to part 121 after spring 1997 under the Commuter Rule of that time. Most reports on major accidents (hull losses or non-hull losses that resulted in multiple fatalities) provided extensive data on flight crews' duty tours and recent rest periods, which facilitated relatively strong assessments.

The FAA's Office of Accident Investigation and Prevention (AVP) rated each accident by conducting a scoring process similar to that conducted by the Commercial Aviation Safety Team (CAST), a well-documented and well understood procedure. All the accidents that have had final National Transportation Safety Board (NTSB) reports published have been scored against the CAST safety enhancements. AVP used the NTSB recommendations along with narratives, probable cause, contributing factors and other pertinent data to score the accidents.

When these accidents were not well defined in the probable cause or contributing factors statements of the NTSB reports, AVP used a Joint Implementation Monitoring Data Analysis Team (JIMDAT)-like method. The JIMDAT-type scoring system is from 0 to 5, and the score is based on the likelihood that a proposed action would have mitigated that accident. The level and percentage of effectiveness criteria follows:

5- 90% effectiveness. The proposed requirement directly addresses the NTSB causal factors and would very likely prevent the accident in the future.

4- 75% effectiveness. The proposed requirement directly addresses the majority of the NTSB causal factors and would probably prevent or is likely to reduce the risk of the respective accident, given the circumstances that prevailed.

3- 50 % effectiveness. The proposed requirement directly addresses one of several NTSB causal factors and is likely to reduce the risk of the respective accident, given the circumstances that prevailed.

2- 35% effectiveness. The proposed requirement generally addresses the NTSB causal factors and is likely reduce the risk of the respective accident, given the circumstances that prevailed.

1- 15% effectiveness. The proposed requirement is likely to have reduced the risk of the respective accident, given the circumstances that prevailed.

0- 0% effectiveness. The proposed requirement would not reduce the risk of this type of accident in the future.

AVP applied the above methodology to the details of each such pilot fatigue accident to reach a qualitative assessment of the NPRM's potential capacity to avoid each pilot fatigue accident. The qualitative assessments ranged from zero (0) to low (1), moderate (3), high (4) and very high (5). The qualitative assessments then were converted to quantitative effectiveness scores as follows: zero; 15%; 35%; 50%; 75%; and 90%. The effectiveness scores yielded about 8 accidents avoided over 20 years (see Technical Report submitted to the docket for the scoring results of the above accidents used in this analysis). According to this scoring, the proposed rule would be 40 percent effective at preventing passenger airplane accidents where pilot fatigue was a contributing factor and would be 58 percent effective at preventing cargo airplane accidents where pilot fatigue was a contributing factor.

Accordingly, the above estimate of the benefits of avoiding passenger airplane accidents where pilot fatigue was a causal factor have been reduced to 40 percent of their above stated values. The undiscounted mean benefit was reduced from $1.403 billion to $572.1 million and the maximum undiscounted benefit was reduced from $7.225 billion to $2.890 billion. The mean present value of the benefit was reduced from $1.006 billion to $402.5 million and the maximum present value benefit was reduced from $5.322 billion to $2.129 billion.

Next, the estimated benefits of avoiding cargo airplane accidents were reduced to 58 percent of their above stated values. The undiscounted mean benefit was reduced from $150.5 million to $87.3 million and the maximum undiscounted benefit was reduced from $614.8 billion to $356.6 million. The mean present value of the benefit was reduced from $105.7 million to $61.3 million and the maximum present value benefit was reduced from $446.2 million to $258.8 million.

The estimated benefit of avoiding passenger and cargo airplane accidents would be a mean value of $659.4 million ($463.8 million, present value).

Additional Benefits

The FAA has investigated other areas of potential benefit from this proposed rule. These areas are not quantified at this time, but are additional factors that should be considered when deciding whether to proceed with this rule.

The first area is in the area of minor aircraft and equipment damage on the ramp. By necessity, the focus on fatal accidents examines extremely remote events where something in the events leading to the accident did not reliably provide the necessary safety margin or back up. In part the focus on fatal accidents comes from the fact they are investigated in detail, event chains and causes are well defined, and assumptions can be made about cause and effect. However, there is a much larger universe of relatively minor accidents that may involve much larger annual dollar losses than the few fatal accidents that do occur. However, so few of these are investigated in much detail that they tend to be disregarded when looking at new safety regulations.

In the 170 Part 121 accidents from 2004-2008, there were a total of ten events that had a fatality. Overall, 90 fatalities occurred on those ten flights over the course of five years. Using a VSL of $6 million, the monetized value of loss of life is $540 million, and the average value of lost lives is about $100 million per year. This amount is only a small fraction of the overall cost of accidents on airport ramps. One estimate puts the cost of ground accidents and incidents which include injuries, fatalities and property damage at $5 billion per year worldwide. In the U.S. alone, total costs of ramp incidents and accidents exceed $3 billion per year. However, these events are not investigated in detail—i.e., there is a lack of causal information, no human factors report with work chronology, etc.

The fatigue literature suggests that the greatest benefits from fatigue reduction lie in increased productivity and in the reduction of human errors. Thus, we would expect to see a much larger number of events where pilot fatigue is a cause or factor, than is represented by fatal accidents alone. Preliminary research shows that the frequency of ground accidents during the evening (6:00 PM to midnight) and early morning (midnight to 6:00 AM) is higher than the distributions of scheduled takeoffs and landings would suggest. We observe a similar relationship when we look at Aviation Safety Reporting System (ASRS) reports citing pilot fatigue and related topics.

Of course not all the ground accidents involve pilot error, and not all instances of pilot error are cause by fatigue. However, the data on when these accidents occur suggest they are more prevalent when the potential for fatigue is greatest. In addition, the types of events such as taxiing a wing tip into another aircraft or gate, are symptomatic of poor decision making, poor spatial judgment, a focus on completing the flight quickly and other factors which may be more prevalent when fatigued. If even only a few percent of the losses from ground accidents are caused by pilot fatigue, the annual losses are large Three percent would be $90 million per year. These data suggest that the scope of accidents/incidents for valuing safety needs to be expanded to account for losses due to ground events where appropriate.

The second area is in the value of having well rested (and well-trained) pilots in the cockpit to solve minor problems before they become accidents. The aviation system is extremely complex, and aircraft are extremely complex machines. It is also extremely safe. When an accident occurs, it is generally the result of a long chain of multiple failures. The flightcrew in the cockpit is generally the last opportunity to break the chain and prevent an accident. It is well established that fatigued people are less likely to quickly and efficiently diagnose and solve problems than well-rested people. Every day, small events and mishaps are dealt with by the cockpit crew and they never become accidents, or the outcome is somewhat mitigated by the quick action of the crew. (The Flight 1549 that landed safely in the Hudson River is an example of how very quick reaction and decision making can avert catastrophes.) Some small number of incidents and accidents caused by things other than fatigue or human error maybe could have been prevented or mitigated if the crew had quickly behaved differently. While we have documented the likely size of the accident problem with fatigue as a factor, it is not possible to estimate the impact of increased problem solving capability from fewer fatigued pilots. It is, however, real and significant.

Sensitivity Analysis: Value of Statistical Life Estimates for FAA Regulatory Programs

Complex analyses for difficult public policy decisions typically employ sensitivity analyses to allow decision makers to see the impact of different values of key variables, to see how those different values impact the results of the analysis. The value of a statistical life (VSL) is an important policy measure as it is primarily used when federal agencies look to compare the costs and benefits of potential investment and regulatory policies and programs. In this regulatory impact analysis, FAA presented total benefits based on VSLs of $6 million, as suggested by 2009 guidance from DOT, and consistent with OMB Circular A-4. If $8.4 million were used for VSL, the undiscounted benefits would be $837 million and the present value of those benefits would be $589 million. A VSL value of $8.4 million is consistent with recent literature[14][15]. The FAA requests public comment on whether decision-makers should

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[14] *See* Thomas J. Kniesner, W.Kip Viscusi, and James P. Ziliak, "Policy Relevant Heterogeneity in the Value of Statistical Life: New Evidence from Panel Data Quantile Regressions," Journal of Risk Analysis, Vol.40, No. 1, pp. 15-31

[15] W. Kip Viscusi, "The Heterogeneity of the Value of Statistical Life: Introduction and Overview," Journal of Risk Analysis, Vol.40, No. 1, pp. 1-13

consider using a VSL higher or lower than $6 million to evaluate commercial aviation safety proposals.

COST ANALYSIS

Cost Overview

The total estimated cost of the proposed rule is $1.25 billion ($804 million present value using a seven percent discount rate) for the ten year period from 2013 to 2022. The FAA classified costs into four main components and estimated the costs for each component.[16] We obtained data from various industry sources; the sources of the data used in cost estimation are explained in each section. We were very fortunate that several carriers ran two alternatives to the proposed rule through their crew scheduling programs. Their estimates provided some comparison data to calibrate and validate our costing approach. Without their help, we would have likely missed some cost elements. The Cost Summary Table below identifies the four main cost components. Flight operations cost makes up about 60 percent of the total cost of the rule. Each of the main cost components are explained in-depth in the following sections of this document.

Cost Summary

Cost Area	Nominal Cost (in $ millions)	Present Value Cost (in $millions)
Flight Operations	$760.3	$484.2
Scheduling Reliability	$4.9	$3.0
Fatigue Training Costs	$262.3	$167.2
Cost of Rest Facilities	$226.6	$149.1
Total Cost	$1,254.1	$803.5

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[16] The FAA also calculated alternative scheduling costs, which comprise the largest cost component of the proposed rule. Discussions of these alternatives follow the main cost section.

In addition to the costs presented in the Cost Summary Table, there may be costs of a fatigue risk management system (FRMS). The FAA is not imposing an FRMS program requirement on Part 121 carriers, but is allowing them the option of developing and implementing such a program. Operators might do this for ultralong flights, which have flight time over 16 hours. Operators might develop an FRMS program as an alternative to the flight and duty period rules proposed by this rulemaking when the crew scheduling cost savings equal or exceed the costs of the FRMS program. The FAA estimates that an FRMS program would cost between $0.8 and $10.0 million for each operator over ten years. The FAA believes that about 35 operators have at least partially adopted an FRMS program at this time. The FAA estimates the total cost would be $205.7 million ($144.9 million present value), which would be more than offset by a reduction in crew scheduling costs. Accordingly, the cost is not added to the total costs imposed by this rule. The FAA calls for comment on this aspect of the proposal as it has not assigned a cost to the cumulative maximums.[17]

Flight Operations – Overview

The flight operations cost component of the proposed rule is composed of five sub-components: crew scheduling costs, cost to supplement the flight engineer on augmented operations, crew management system computer programming costs, cost savings of reduced reserves, and cost savings of the elimination of the flight time limit for

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[17] Cumulative maximums are limitations on the amount of duty or flight time that flightcrew members are allowed to work over a period of time greater than a single duty period; for instance, the proposed rule sets a maximum of 65 duty hours in any seven-day period and a maximum of 200 duty hours in a 28-day period.

augmented operations. Table 5 provides a summary of the five sub-components of the flight operations cost. Each of the sub-components is explained in-depth in the following sections of the document.

Table 5: Summary of Flight Operations Costs

Cost Sub-Component	Nominal Cost (millions)	PV Cost (millions)
Crew Scheduling (Resource Cost Only)	$ 1,366.7	$ 854.2
Augmented - Suppplement FE	$ 66.7	$ 40.9
Computer Programming	$ 10.0	$ 8.1
Reduced Reserves	($ 231.7)	($ 142.1)
Augmented - Eliminate Flight Time Limit	($ 451.4)	($ 276.9)
Total Flight Operations	**$ 760.3**	**$ 484.2**

Flight Operations – Crew Scheduling

Analysis of Crew Schedule Data

Six air carriers[18] provided actual crew schedule data to the FAA to assist in the cost analysis of the Flightcrew Member Duty and Rest Requirements Rulemaking. The data consisted of one spring month in 2009 and one summer month in 2009 of actual work history for each flightcrew member employed by each carrier. The specific months varied by carrier. The data included all duty time and flight time worked by each flightcrew member, and included both lineholder and reserve pilots.

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[18] Two of the carriers included data for related carriers operating under multiple business names.

The individual flightcrew member work histories were used to construct baseline summary data for each carrier. The total numbers of duty periods, duty hours, flight hours, and flight segments were summarized. The summary data were divided by the number of flightcrew members in each dataset to produce the average number of duty periods, duty hours, flight hours, and flight segments per flightcrew member per month. The baseline data was later used to estimate the number of noncompliant hours under the proposed rule.

Three types of crew scheduling limits were examined: flight duty, rest, and flight time limits. Only limits relating to individual flight duty periods were applied. Cumulative limits were not applied due to data limitations.. Flight duty limits impose a maximum number of hours that a flightcrew member may be on flight duty, based on the number of flight segments flown during the flight duty period (for unaugmented operations only), the starting time of the flight duty period, and, for augmented operations only, the rest facility onboard the aircraft and the number of crew operating the flight. Rest limits require that a flightcrew member have received a minimum number of rest hours (hours free from all duty) prior to beginning a flight duty period and vary depending on geographic location (domestic or international flights).[19] Flight limits impose a maximum number of hours that a flightcrew member may operate an aircraft during a given flight duty period and vary depending on the starting time of the flight duty period (for unaugmented operations only).

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[19] In the context of proposed minimum rest limits, “domestic” refers to a flight duty period beginning in the 48 contiguous states, territories, and District of Colombia. “International” refers to a flight duty period beginning outside of the 48 contiguous states, territories, and District of Colombia.

A computer program was used to apply flight duty, rest, and flight time limits to the actual crew schedule data. First, the maximum flight duty limits were applied to each individual duty period. If the flight duty period exceeded the relevant flight duty limit, the duty period was truncated at the limit. Next, the minimum rest limits were applied to each individual duty period. If a flight duty period was not preceded by the relevant minimum number of rest hours, then the preceding flight duty period was truncated at the point where the minimum number of rest hours was sufficient for the flight duty period in question. Finally, the flight limits were applied to each individual flight duty period. If the sum of all flight time within a flight duty period exceeded the relevant flight limit, the last flight segment of the flight duty period was eliminated from the data, with the elimination of flight segments continuing backwards, if necessary, until the sum of all flight time within the flight duty period was lower than the flight limit. For all of the types of limits, if the flight duty period was truncated while a flight segment was underway, then the entire flight segment was eliminated from the data.

The application of the proposed flight duty, rest, and flight time limits resulted in modified flightcrew member work histories. These modified work histories were used to construct modified summary data for each carrier, similar to the baseline summary data. The modified number of duty periods, duty hours, flight hours, and flight segments also were summarized. The modified summary data was divided by the number of flightcrew members in each dataset to produce the average number of duty periods, duty hours, flight hours, and flight segments per flightcrew member per month.

The modified average number of flight hours per flightcrew member was compared to the baseline average number of flight hours per flightcrew member for each carrier. The difference between the two numbers represented the average number of flight hours per flightcrew member that were not compliant with the applied flight duty, rest, and flight time rules. The assumption is that these extra hours result in needing to either hire new pilots or pay existing pilots for more hours of duty. This is a very conservative initial estimate, which is later adjusted.

The FAA evaluated the proposed flight duty, rest, and flight time limits to produce an estimated crew scheduling cost for the entire air transport industry. Table 6 details the most significant differences between the proposed rule and current Part 121 rules.

Table 6: Comparison of Proposed Rule to Current Part 121

Scenario	Rest Time		Duty Time		Flight Time	
	Minimum Rest Prior to Duty - Domestic	**Minimum Rest Prior to Duty - International**	**Maximum Flight Duty Time - Unaugmented**	**Maximum Flight Duty Time - Augmented**	**Maximum Flight Time - Unaugmented**	**Maximum Flight Time - Augmented**
Current Part 121	Daily: 8-11 depending on flight time	Minimum of 8 hours to twice the number of hours flown	16	16-20 depending on crew size	8	8-16 depending on crew size
NPRM	9	9	9-13 depending on start time and number of flight segments	12-18 depending on start time, crew size, and aircraft rest facility	8-10 depending on FDP start time	None

Scenario	Rest Time		Duty Time		Flight Time	
	Minimum Rest Prior to Duty - Domestic	Minimum Rest Prior to Duty - International	Maximum Flight Duty Time - Unaugmented	Maximum Flight Duty Time - Augmented	Maximum Flight Time - Unaugmented	Maximum Flight Time - Augmented
Current Part 121	Daily: 8-11 depending on flight time	Minimum of 8 hours to twice the number of hours flown	16	16-20 depending on crew size	8	8-16 depending on crew size
NPRM	9	9	9-13 depending on start time and number of flight segments	12-18 depending on start time, crew size, and aircraft rest facility	8-10 depending on FDP start time	None

Cost Estimates Using Crew Schedule Data

All Part 121 air carriers in the U.S. air transport industry were categorized into seven groups based on the size of the aircraft type with the most block hours in 2008[20] and operating characteristics. Table 7 defines the groups based on aircraft size and operating characteristics. The number of air carriers in each group and number of flightcrew members in each group are also presented.

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[20] Department of Transportation, Bureau of Transportation Statistics, Air Carrier Summary Data (Form 41 and 298C Summary Data), T2: U.S. Air Carrier Traffic and Capacity Statistics by Aircraft Type, 2008.

Table 7: Air Carrier Groups for NPRM Cost Analysis

Group		Aircraft Type with Most Block Hours	Part 121 Air Carriers	Part 121 Flightcrew Members
1	Large Cargo Carrier	Aircraft > 100 seats equivalent	26	10,125
2	Commercial Passenger Carrier	Aircraft > 100 seats	8	39,406
3	Low Cost Carrier	Aircraft > 100 seats	9	11,260
4	Regional Passenger Carrier	Aircraft 20 < seats < 100	30	20,980
5	Small Cargo Carrier	Aircraft < 100 seats equivalent	3	236
6	Small Passenger Carrier	Aircraft < 20 seats	4	281
7	Charter Passenger Carrier	Aircraft > 100 seats	12	1,230
Total			92	83,518

Source: FAA OPSS, October 2009

Each of the six air carriers that provided crew schedule data to the FAA was assigned to one of the seven air transport industry groups. Each of the industry groups was represented in the data provided to FAA, except for the small passenger, small cargo, and charter passenger groups. The crew schedule data provided to the FAA represented 23 percent of all Part 121 flightcrew members, as shown in Table 8.

Table 8: Coverage of Industry

Total Part 121 Flightcrew Members	Flightcrew Members in Data Provided to FAA	Coverage Share
83,518	**19,529**	**23.4%**

Three industry groups were not represented in the data provided to the FAA and were assigned to a comparison group for purposes of cost estimation. The comparison group is the industry group that most closely resembles the unrepresented industry group. Table 9 presents the comparison group for each of the seven industry groups.

Table 9: Comparison Groups

Group	Comparison Group
Large Cargo	Large Cargo
Commercial Passenger	Commercial Passenger
LCC	LCC
Regional	Regional
Small Cargo	Large Cargo
Small Passenger	Regional
Charter Passenger	Large Cargo

To determine the crew scheduling costs of the proposed rule, the number of noncompliant flight hours for each air carrier in the air transport industry was first calculated. The number of noncompliant flight hours for each carrier was calculated by multiplying the number of flightcrew members employed by the carrier by the average number of noncompliant flight hours per flightcrew member for the carrier's relevant comparison group. Table 10 presents the number of noncompliant flight hours and their share relative to the baseline for the proposed rule.

Table 10: Noncompliant Flight Hours

Noncompliant Flight Hours	Share of Baseline
2,385,702	4.8%

After the total number of noncompliant flight hours was calculated for each carrier, costs were calculated based on the average hourly salary for each flightcrew member, for each carrier. The primary source of salary data was a 2006 report by AIR, Inc, an aviation industry publication. The report listed both annual salary and estimated credit hours for many carriers. This information was used to estimate the average hourly salary per flightcrew member. If salary data were unavailable for a carrier, the average hourly salary per flightcrew member for that carrier's industry group was used as a proxy. The average hourly salaries were updated to 2009 values using the Air Transport Association (ATA) Passenger Airline Cost Index. The labor component of the cost index was used to update the salaries from Q3 2006 to Q3 2009.[21] Table 11 presents the average hourly salary per flightcrew member for each industry group.

Table 11: Average Hourly Salary

Group	Average Hourly Salary
Large Cargo	$121
Commercial Passenger	$129
LCC	$107
Regional	$60
Small Cargo	$55
Small Passenger	$45
Charter Passenger	$92

The average hourly salary per flightcrew member for each carrier was multiplied by the noncompliant flight hours for each carrier, resulting in an estimated salary cost for each carrier. After estimating the additional crew scheduling salary cost, it was necessary

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[21] Q3 2009 data was the most recent available at the time of publication.

to calculate the additional hotel and per-diem costs that would be incurred by carriers. During the rulemaking, one carrier had estimated its expected crew scheduling costs resulting from the flight duty, rest, and flight limits of one alternative to the proposed rule. As part of this analysis, the carrier allocated its total crew scheduling costs to salary, hotel, and per diem categories. We have used their costs proportions to estimate hotel and per diem for other scenarios.

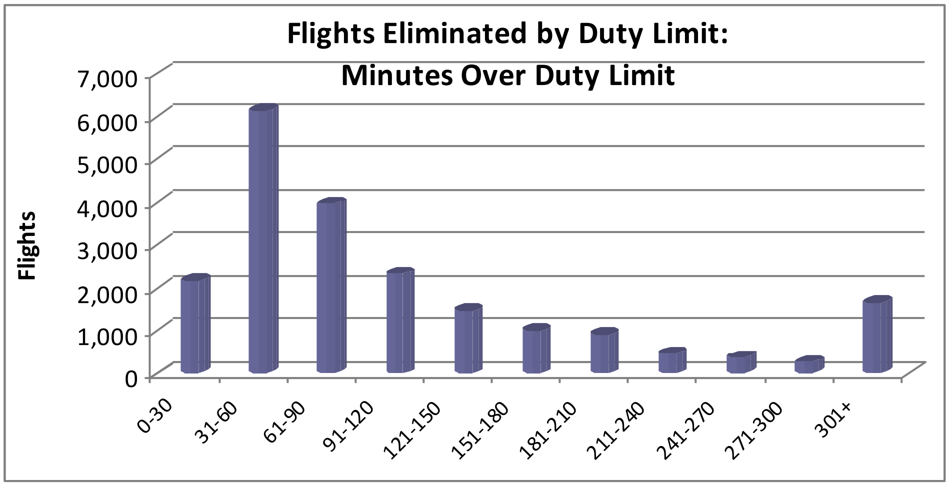
The individual carrier salary, hotel, and per-diem costs were summarized based on the seven industry groups to result in unadjusted additional annual crew scheduling costs resulting from the application of NPRM flight duty, rest, and flight time limits, as shown in Table 12.

Table 12: Unadjusted Crew Scheduling Costs

Year	Nominal Cost (millions)	PV Cost (millions)
2013	$ 338.3	$ 276.2
2014	$ 338.3	$ 258.1
2015	$ 338.3	$ 241.2
2016	$ 338.3	$ 225.4
2017	$ 338.3	$ 210.7
2018	$ 338.3	$ 196.9
2019	$ 338.3	$ 184.0
2020	$ 338.3	$ 172.0
2021	$ 338.3	$ 160.7
2022	$ 338.3	$ 150.2
Total	**$ 3,383.4**	**$ 2,075.6**

The FAA believes that substantial opportunity for re-optimization exists because many of the flight segments that are eliminated for non-compliance with the proposed rule are only non-compliant by small amounts of time. Approximately 86 percent of the eliminated flights are due to non-compliance with duty limits, rather than flight or rest limits. The FAA examined the amount of time by which the duty period associated with each eliminated flight segment exceeded the maximum allowable duty time. Chart 1 presents these results. Nearly 40 percent of flights were eliminated due to their duty period exceeding the maximum allowable duty time by less than 60 minutes.

Chart 1: Duty Period Non-Compliance for Eliminated Flights



The FAA believes the crew scheduling costs calculated using this methodology substantially overestimate the probable actual cost impact of the proposed rule. Most airlines employ computer programs to optimize crew schedules – to minimize the number of crew hours, and hotel and per diem costs it takes to fly a given flight schedule within imposed constraints. The FAA accordingly has developed a methodology to adjust the estimate based on total non-compliant hours to a more realistic representation of costs after re-optimization. We ask for comments on the cost adjustments described in the next section and request a detailed explanation or justification for any and all comments.

Crew Scheduling Cost Adjustments

To approximate the reductions in cost that will occur when airlines optimize crew schedules following implementation of the rule, the FAA made several adjustments to the crew scheduling costs presented in Table 12. These adjustments include both short-term and long-term optimization that the FAA believes is likely to occur.

The FAA applied a short-term optimization factor of 25 percent to the unadjusted costs. This discount off of raw costs approximates the savings expected from the computer models used to build schedules; flight schedules will be rearranged into new trips that meet the new constraints of the rule. Typically, industry will experience from 10 percent to 40 percent savings from reoptimizing in this fashion. FAA selected a factor of 25 percent because it approximates the difference in costs submitted by a sample of carriers to FAA when they evaluated an alternative to the proposed rule, using their computer models, to the costs estimated by the FAA using the same cost estimation process described previously. Table 13 presents the annual costs after short-term optimization.

Table 13: Crew Scheduling Costs after Short-Term Optimization

Year	Optimization Factor	Nominal	PV
2013	25%	$ 253.8	$ 207.1
2014	25%	$ 253.8	$ 193.6
2015	25%	$ 253.8	$ 180.9
2016	25%	$ 253.8	$ 169.1
2017	25%	$ 253.8	$ 158.0
2018	25%	$ 253.8	$ 147.7
2019	25%	$ 253.8	$ 138.0
2020	25%	$ 253.8	$ 129.0
2021	25%	$ 253.8	$ 120.6
2022	25%	$ 253.8	$ 112.7
Total		**$ 2,537.5**	**$ 1,556.7**

After determining the crew scheduling costs after short-term optimization, FAA examined the salary component of the crew scheduling costs and identified the share that would be additional pay to existing crews versus salary for new hires. The initial shares are identical to those provided by one carrier that submitted a detailed cost estimate to FAA of an alternative to the proposed rule. Over time, FAA believes that the share of pay to existing crews will increase while the share of new hire salary will decrease, because carriers will continue to schedule crews ever more efficiently. Table 14 provides the annual shares of the crew scheduling cost components.

Table 14: Crew Scheduling Cost Components

Year	Existing Crews	New Hires	Hotel & Per Diem
2013	41%	48%	11%
2014	43%	46%	11%
2015	45%	44%	11%
2016	47%	42%	11%
2017	49%	40%	11%
2018	51%	38%	11%
2019	53%	36%	11%
2020	55%	34%	11%
2021	57%	32%	11%
2022	59%	30%	11%

Once the share of salary costs between the existing crews and new hires was determined, FAA identified additional long-term optimization factors, independent of the previously described short-term optimization. The long-term optimization factors reflect changes to crew bases, flight schedules, and other similar changes that will be implemented over a number of years. These also include potential adjustments to contracts between pilots and airlines that govern pay and working conditions. In conjunction with this step, FAA identified costs as either transfer costs or resource costs. The sum of these represents the financial impact on the carrier.

Transfer costs are defined as temporary cost increases resulting from short-term disruptions for the industry and its participants. These result in financial transfers between the carriers and flightcrew members. Resource costs are defined as true costs to society, due to inefficient use of resources. (The key difference between resource costs and transfers is whether the pilot ends up with free time that can be put to other productive uses. If a pilot does end up with additional free time for the same pay as before, this represents a transfer between the carrier and the pilot.) Tables 15 and 16 identify the long-term optimization factors, transfer costs, and resource costs for existing crews and new hires, respectively. Over the longer term, we expect that carriers will be able to improve scheduling efficiency of existing crew members. In the case of new pilots, there is less of an opportunity to improve scheduling efficiency.

Table 15: Long-Term Optimization of Additional Pay to Existing Crews

Year	Optimization Factor	Transfer Cost	Resource Cost
2013	60%	67%	33%
2014	40%	50%	50%
2015	20%	0%	100%
2016	20%	0%	100%
2017	20%	0%	100%
2018	20%	0%	100%
2019	20%	0%	100%
2020	20%	0%	100%
2021	20%	0%	100%
2022	20%	0%	100%

Table 16: Long-Term Optimization of Pay to New Hires

Year	Optimization Factor	Transfer Cost	Resource Cost
2013	95%	0%	100%
2014	90%	0%	100%
2015	80%	0%	100%
2016	80%	0%	100%
2017	80%	0%	100%
2018	80%	0%	100%
2019	80%	0%	100%
2020	80%	0%	100%
2021	80%	0%	100%
2022	80%	0%	100%

Table 17 presents the total crew scheduling costs, including salary to existing crews and new hires, hotel, and per-diem. The costs are categorized as either transfer or resource costs. The final reported costs of the proposed rule include only the resource costs from Table 17, as they represent the true cost of the rule to society.

Table 17: Final Crew Scheduling Costs

Year	Transfer Costs		Resource Costs	
	Nominal Cost (millions)	PV Cost (millions)	Nominal Cost (millions)	PV Cost (millions)
2013	$ 64.4	$ 52.5	$ 165.5	$ 135.1
2014	$ 33.6	$ 25.6	$ 156.0	$ 119.0
2015	$ 0.0	$ 0.0	$ 141.3	$ 100.8
2016	$ 0.0	$ 0.0	$ 138.3	$ 92.1
2017	$ 0.0	$ 0.0	$ 135.2	$ 84.2
2018	$ 0.0	$ 0.0	$ 132.2	$ 76.9
2019	$ 0.0	$ 0.0	$ 129.1	$ 70.2
2020	$ 0.0	$ 0.0	$ 126.1	$ 64.1
2021	$ 0.0	$ 0.0	$ 123.0	$ 58.5
2022	$ 0.0	$ 0.0	$ 120.0	$ 53.3
Total	**$ 97.9**	**$ 78.2**	**$ 1,366.7**	**$ 854.2**

Flight Operations – Additional Pilot to Supplement Flight Engineer

Carriers currently operating flights in excess of eight hours with a flightcrew of two pilots and one flight engineer will incur additional pilot salary costs on these flights under the proposed rule. Under current Part 121 rules, flight engineers are considered to be a crewmember for purposes of determining whether a flight can operate under augmented flight and duty rules. The proposed rule will not allow flight engineers to be considered as crewmembers when determining whether a flight can operate under augmented flight and duty rules. Therefore, carriers will need to add another pilot to the flightcrew for those flights that currently exceed eight hours and have a flightcrew of two pilots and a flight engineer.

The first step to estimating the cost impact of this aspect of the proposed rule was to examine the crew schedule data provided to the FAA and identify the flights affected by this rule change. Flights exceeding eight hours with a two pilot flightcrew were identified. Only those flights on aircraft types that utilize a flight engineer were considered. The only flights that met these criteria were operated by carriers in the large cargo group. The number of flight hours associated with these flights was then annualized. The annual number of flight hours was divided by the number of flight engineers for the relevant carriers to produce an average number of flight hours affected by the rule change per flight engineer. The result is 29.1 flight hours per flight engineer per year. The only aircraft types operated by flight engineers in the sample data that FAA received from the carriers are Boeing 727 and Boeing 747 aircraft.

The average number of flight hours affected per flight engineer was extrapolated to the entire air transport industry using the number of flight engineers listed on each air carrier's operating certificate in OPSS. The average number of flight hours affected per flight engineer was multiplied by the number of flight engineers at each carrier. The result represents the total number of flight hours that must be flown by a pilot to comply with the proposed rule. The total number of flight hours for each carrier was multiplied by the average hourly pilot salary for the carrier's industry group to obtain a total estimated cost of this aspect of the proposed rule. Table 18 summarizes the results by industry group. Industry groups that did not include a carrier with at least one flight engineer were excluded from Table 18.

Table 18: Annual Cost of Adding a Pilot to Supplement Flight Engineer on Augmented Flights

Industry Group	Flight Engineers	Flight Hours Affected	Average Pilot Hourly Salary	Additional Pilot Salary Cost (millions)
Large Cargo	1,648	49,020	$121	$5.9
Charter Passenger	92	2,715	$92	$0.3
Commercial Passenger	125	3,690	$129	$0.5
Total		**55,425**	▨	**$6.7**
Note: Analysis was conducted on a carrier-specific basis. Aggregated results are presented here.				

The nominal annual cost of adding a pilot to supplement the flight engineer on augmented flights is $6.7 million. The nominal cost for the period of analysis is $66.7 million and the present value cost for the period of analysis is $40.9 million, as shown in Table 19.

Table 19: Cost of Adding a Pilot to Supplement Flight Engineer on Augmented Flights

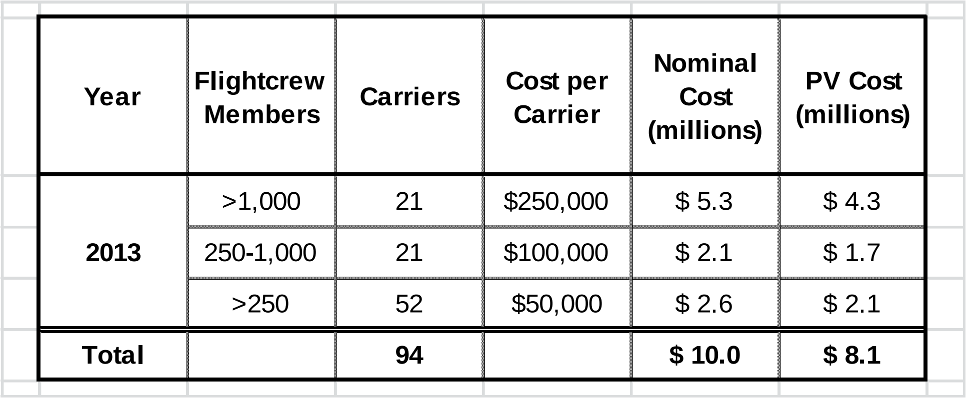
Year	Nominal Cost (millions)	PV Cost (millions)
2013	$6.7	$5.4
2014	$6.7	$5.1
2015	$6.7	$4.8
2016	$6.7	$4.4
2017	$6.7	$4.2
2018	$6.7	$3.9
2019	$6.7	$3.6
2020	$6.7	$3.4
2021	$6.7	$3.2
2022	$6.7	$3.0
Total	**$66.7**	**$40.9**

Flight Operations – Computer Programming

Carriers will incur computer programming costs as they will need to update their crew management systems and their schedule optimization systems with the constraints imposed by the proposed rule. This will be a one-time cost incurred in 2013 as carriers update their computer systems. Computer programming costs were estimated for each individual carrier, based on the number of flightcrew members listed on the carrier's operating certificate.

Carriers were assigned to one of three groups based on the number of flightcrew members. Costs were estimated based on the number of person-days required to complete the computer programming and a daily professional staff cost of $2,500. Table 20 presents the nominal and present value computer programming costs. We invite specific comment on this estimate of the expected computer programming costs for carriers.

Table 20: Computer Programming Costs



Year	Flightcrew Members	Carriers	Cost per Carrier	Nominal Cost (millions)	PV Cost (millions)
2013	>1,000	21	$250,000	$ 5.3	$ 4.3
	250-1,000	21	$100,000	$ 2.1	$ 1.7
	>250	52	$50,000	$ 2.6	$ 2.1
Total		**94**		**$ 10.0**	**$ 8.1**

Flight Operations – Cost Savings from Reduced Reserves

The proposed rule is designed to reduce the risk of fatigued flightcrew members by limiting the maximum number of hours they are permitted to be on duty, the number of hours they actually fly during duty periods, and by ensuring that they receive adequate rest periods before reporting for duty. It is expected that the proposed rule will result in better-rested flightcrew members. The proposed rule will reduce flight crew member fatigue, thus reducing the use of sick time. When a flightcrew member is scheduled for duty and calls in sick or fatigued, the airline must use a reserve flightcrew member to complete the scheduled duty. The proposed rule will reduce the use of reserve flightcrew members to cover fatigue-induced sick call-ins by flight crew members, which will reduce the flight operations cost associated with fatigue issues for carriers.

While the precise share of current sick time attributable to fatigue is unknown, it is most likely greater than zero. Similarly, while the precise amount by which the proposed rule will reduce sick time is unknown, it is also most likely greater than zero. For the purposes of this analysis, FAA assumes that sick time accounts for five percent of total industry flightcrew member pay. The proposed rule is expected to reduce the use of sick time by five percent. The nominal value of the cost savings is $231.7 million ($142.1 million present value) over the ten-year period of analysis. Table 21 presents the annual cost savings.

Table 21: Reduced Reserves Cost Savings

Year	Nominal Cost Savings (millions)	PV Cost Savings (millions)
2013	$ 23.2	$ 18.9
2014	$ 23.2	$ 17.7
2015	$ 23.2	$ 16.5
2016	$ 23.2	$ 15.4
2017	$ 23.2	$ 14.4
2018	$ 23.2	$ 13.5
2019	$ 23.2	$ 12.6
2020	$ 23.2	$ 11.8
2021	$ 23.2	$ 11.0
2022	$ 23.2	$ 10.3
Total	**$ 231.7**	**$ 142.1**

Flight Operations – Cost Savings from Augmented Operations

The proposed rule eliminates the existing maximum flight time limit for augmented operations, which creates a potential cost-saving opportunity for carriers. Carriers are required to operate some flights with four flightcrew members under existing maximum flight time limits. Some of these flights could be operated with three flightcrew members under the proposed rule, which would reduce carriers' flight operations costs.

The existing maximum flight time limit for flag and supplemental carriers is 12 hours for three flightcrew members and 16 hours for four flightcrew members. Although there are no maximum flight time limits in the proposed rule for augmented operations, flightcrew members' flight time will be limited in practice by maximum flight duty time limits. The proposed rule sets the maximum flight duty time for a flightcrew member when operating a flight with three flightcrew members at 16 hours for flights on an aircraft with a Class 1 rest facility and when the flight duty period begins between 0700-1259. This maximum flight duty time limit is lower if the aircraft has a lesser-quality rest facility and/or if the flight duty period begins at an earlier or later time.

To determine the potential cost savings resulting from the elimination of augmented maximum flight time limits, the FAA analyzed actual flightcrew member schedule data from six carriers. The data included complete duty and flight records for every flightcrew member (lineholder and reserve) for one spring month and one summer month in 2009. Due to the limited sample size, the FAA needed to make several assumptions and the resulting potential cost estimate is highly uncertain.

First, only flights conducted with four crewmembers with a flight duration of 12 to 14 hours were considered for potential cost savings. Flights of less than 12 hours were not considered because flag and supplemental carriers are allowed to operate flights of less than 12 hours with three flightcrew members under existing maximum flight time limits. Flights of more than 14 hours were not considered because the maximum flight duty time for a flightcrew member under the proposed rule is 16 hours when operating a flight augmented with one additional flightcrew member. The two hour difference is accounted for by check in preceding the flight and check out time following the flight. To the extent that actual check in/check out is greater than or less than the assumed two hours, this potential cost savings estimate may overestimate or underestimate the actual cost savings.

Second, it is assumed that flightcrew member labor agreements will permit the carriers to reduce the number of flightcrew members from four to three. To the extent that labor agreements restrict the flexibility of carriers to reduce the number of flightcrew members on these flights, this potential cost savings estimate will overestimate the actual cost savings.

Third, it is assumed that the crew scheduling needs of carriers will permit them to reduce the number of flightcrew members from four to three. To the extent that carriers desire to operate a flight with four flightcrew members rather than three flightcrew members for operational or schedule reliability purposes, this potential cost savings estimate will overestimate the actual cost savings.

Fourth, to extrapolate the potential cost savings of those carriers for which FAA had data to the entire US air transport industry, it was necessary to assume that the scheduling practices of other carriers were similar to the scheduling practices of those carriers for which FAA had data. If the scheduling practices of the remainder of the US air transport industry materially differ from the scheduling practices of those carriers for which FAA had data, this estimate of potential cost savings may over- or understate the actual cost savings.

To estimate the potential cost savings of those carriers for which FAA had data, flight segments of 12 to 14 hours operated by four flightcrew members were identified. Four carriers operated flights that met these criteria. The carriers represented the commercial passenger and large cargo industry groups. For the flights that met the criteria, the following data was collected: flight hours, flight duty period start hour, and aircraft rest facility.

A distribution of flight hours by flight duty period start hour and aircraft rest facility was calculated. The share of flight hours for which the maximum flight duty period limit applied (16 hours) was used to adjust the number of flight hours. This adjusted number of flight hours represented a realistic number of flight hours that could be reduced from four flightcrew members to three flightcrew members based on maximum flight duty period constraints. Table 22 displays the distribution of flight hours that was used to make the flight hours adjustment.

Table 22: Flights between 12 and 14 Hours Duration Operated by Four Flightcrew Members

Flight Duty Period Start	Aircraft Rest Facility	Share of Flight Hours	NPRM Maximum Flight Duty Time
0000-0559	**1**	13.3%	14
0000-0559	**2**	14.9%	13
0600-0659	**1**	0.1%	15
0600-0659	**2**	0.0%	14
0700-1259	**1**	23.5%	16
0700-1259	**2**	16.9%	15.5
1300-1659	**1**	0.6%	15
1300-1659	**2**	6.8%	14
1700-2359	**1**	17.0%	14
1700-2359	**2**	6.9%	13

Next, the number of adjusted flight hours per flightcrew member was calculated. This was accomplished by dividing the total flightcrew members by the adjusted flight hours. This figure was then annualized. Table 23 presents the annual adjusted flight hours saved per flightcrew member.

Table 23: Annual Adjusted Flight Hours Saved per Flightcrew Member

Industry Group	Hours Saved per Crewmember
Commercial Passenger	10.2
Large Cargo	0.6

The estimate of adjusted flight hours saved per flightcrew member was extrapolated to a subset of the entire US air transport industry. The subset consisted of those passenger carriers that had at least one flight segment exceeding eight hours in the year ended June 2009.[22] The subset also included all carriers in the large cargo and charter passenger industry groups.

While aggregated results are reported in this section, the cost savings estimate was conducted on a carrier-specific basis. The adjusted number of flight hours saved per flightcrew member was multiplied by the total number of flightcrew members for each carrier.[23] The total adjusted flight hours saved per flightcrew member was multiplied by the average hourly salary for that carrier to result in an estimated cost savings. Table 24 presents the results of the potential cost savings by industry group.

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[22] These carriers were determined by FAA analysis of Official Airline Guide (OAG) data.

[23] Flightcrew member data from FAA OPSS.

Table 24: Cost Savings Resulting From Elimination of Maximum Flight Time Limit for Augmented Operations

Industry Group	Flight Hours Eliminated	Average Hourly Salary	Salary Cost Savings (millions)
Large Cargo	5,890	$121	$0.8
Charter Passenger	702	$92	$0.1
Commercial Passenger	321,247	$129	$44.2
Total	**327,839**	▨	**$45.1**

The nominal annual cost savings resulting from the elimination of maximum flight time limits on augmented flights is $45.1 million. The nominal cost savings for the period of analysis is $451.4 million and the present value cost savings for the period of analysis is $276.9 million, as shown in Table 25.

Table 25: Cost Savings Resulting from Elimination of Maximum Flight Time Limit for Augmented Operations

Year	Nominal Cost (millions)	PV (millions)
2013	$45.1	$36.8
2014	$45.1	$34.4
2015	$45.1	$32.2
2016	$45.1	$30.1
2017	$45.1	$28.1
2018	$45.1	$26.3
2019	$45.1	$24.6
2020	$45.1	$22.9
2021	$45.1	$21.4
2022	$45.1	$20.0
Total	**$451.4**	**$276.9**

Flight Operations – Total Cost

The total flight operations cost is composed of the additional crew scheduling costs (flightcrew member salary, hotel, and per diem), plus the cost of supplementing a two-pilot and flight engineer flightcrew with an additional pilot for flights greater than eight hours, plus the computer programming costs, less the cost savings from reduced reserves, and less the cost savings resulting from the elimination of maximum flight time limits for augmented operations. The net nominal value of the total flight operations cost for the period of analysis is $760.3 million, with a present value of $484.2 million. Table 26 presents the annual nominal and present value total flight operations cost. Table 27 provides breakdown of the total flight operations cost by cost sub-component. The FAA asks for comments regarding the flight operations cost, accompanied by a detailed justification.

Table 26: Total Flight Operations Cost

Year	Nominal Cost (millions)	PV Cost (millions)
2013	$ 113.8	$ 92.9
2014	$ 94.4	$ 72.0
2015	$ 79.7	$ 56.8
2016	$ 76.6	$ 51.1
2017	$ 73.6	$ 45.8
2018	$ 70.5	$ 41.1
2019	$ 67.5	$ 36.7
2020	$ 64.5	$ 32.8
2021	$ 61.4	$ 29.2
2022	$ 58.4	$ 25.9
Total	**$ 760.3**	**$ 484.2**

Table 27: Total Flight Operations Cost Summary

Cost Sub-Component	Nominal Cost (millions)	PV Cost (millions)
Crew Scheduling (Resource Cost Only)	$ 1,366.7	$ 854.2
Augmented - Suppplement FE	$ 66.7	$ 40.9
Computer Programming	$ 10.0	$ 8.1
Reduced Reserves	($ 231.7)	($ 142.1)
Augmented - Eliminate Flight Time Limit	($ 451.4)	($ 276.9)
Total Flight Operations	**$ 760.3**	**$ 484.2**

Schedule Reliability

Schedule reliability refers to the accuracy of the scheduled flight duty period compared to the actual flight duty period. Carriers will be required to report the scheduling reliability and pairing-specific reliability to the FAA every two months.[24] The FAA expects carriers to use existing software packages, but carriers will need to incorporate and write new reports, which will warn of potential compliance issues with the proposed rule. The FAA is aware of at least two smaller operators who run schedule reliability programs manually without the support of software. For operators who perform the analysis manually, there would be no software investment required.

Although the reporting requirements would exist for all carriers, the only carriers who would incur any significant cost would be the ones who do not schedule reliably, that is, those having existing unrealistic scheduled vs. actual times. These carriers would have to publish more realistic crew schedules and might have to make some scheduling adjustments. The FAA believes that most carriers are already publishing realistic schedules overall and there would be a minimal impact on these carriers to publish and adjust an existing schedule.

The FAA estimates that each carrier would take about two days to modify their scheduling software to create the required report. We assume that the carriers will use the equivalent of a GS-14, step 5 employee to do this work. With a fully loaded hourly cost of $68.86 and roughly 98 operators, the industry cost would be roughly $108,000

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[24] The report format would be either .xls or .xml.

($88,000 present value) in the first year to make the necessary changes to their scheduling programs.

Each operator would take roughly one more day to prepare, troubleshoot, and submit the report every two months (six reports per year) to the FAA. In this case the FAA assumes that each operator will use the equivalent of a GS-11, step 5 employee with a burdened hourly cost of $33.21. The annual cost per operator is $1,600. For the industry (98 operators) for the ten-year period of analysis, the total cost is $1.6 million ($1.0 million present value).

The FAA believes the burden on it for imposing the reporting requirements would be 2.5 FTE's. We assume these employees will be at the GS-13, step 5 grade level (at Washington DC locality pay rates) at a burdened annual cost of $130,500. The total government cost for the period of analysis is $3.3 million ($2.0 million present value).

The total estimated cost to implement scheduling reliability reporting is $4.9 million ($3.0 million present value.) Annual costs are shown in Table 28.

Table 28: Schedule Reliability Costs[25]

Year	Operator Annual Costs		Government Cost		Implement Report		Total Costs	
	Nominal (millions)	PV (millions)	Nominal (millions)	PV (millions)	Nominal (millions)	PV (millions)	Nominal (millions)	PV (millions)
2013	$0.2	$0.1	$0.3	$0.3	$0.1	$0.1	$0.6	$0.5
2014	$0.2	$0.1	$0.3	$0.2			$0.5	$0.4
2015	$0.2	$0.1	$0.3	$0.2			$0.5	$0.3
2016	$0.2	$0.1	$0.3	$0.2			$0.5	$0.3
2017	$0.2	$0.1	$0.3	$0.2			$0.5	$0.3
2018	$0.2	$0.1	$0.3	$0.2			$0.5	$0.3
2019	$0.2	$0.1	$0.3	$0.2			$0.5	$0.3
2020	$0.2	$0.1	$0.3	$0.2			$0.5	$0.2
2021	$0.2	$0.1	$0.3	$0.2			$0.5	$0.2
2022	$0.2	$0.1	$0.3	$0.1			$0.5	$0.2
Total	**$1.6**	**$1.0**	**$3.3**	**$2.0**	**$0.1**	**$0.1**	**$4.9**	**$3.0**

Fatigue Training - Overview

The proposed rule amends existing flight, duty, and rest regulations by requiring Part 121 operators to develop fatigue training programs. The intent of the fatigue training will be to educate all employees responsible for developing air carrier schedules and safety of flight on the symptoms of fatigue, as well as the factors leading to fatigue and how to mitigate fatigue-based risk. The employees that will be required to complete fatigue training programs include flightcrew members, dispatchers, and management. The fatigue training will be incorporated into existing distance learning programs used by carriers. Table 29 provides a summary of fatigue training costs, which are explained in detail in the following sections.

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[25] Totals may not add due to rounding.

Table 29: Fatigue Training Costs Overview

Employee Group	Nominal Cost (millions)	PV Cost (millions)
Flightcrew Members	$ 234.2	$ 149.3
Dispatchers and Management	$ 28.1	$ 17.9
Total Fatigue Training	**$ 262.3**	**$ 167.2**

Fatigue Training – Flightcrew Members

This section describes the approach used to estimate the fatigue training costs for flightcrew members (captains, first officers, and flight engineers). Initial and recurring fatigue training costs were calculated for all flightcrew members from 2013 to 2022. The primary cost component is salary compensation for the time that flightcrew members spend in fatigue training. There will be no hotel or per-diem costs because the training will be conducted through distance learning programs.

Flightcrew members' data were derived from the FAA Operating Specification Subsystem (OPSS), which reports the number of flightcrew members as recorded on each carrier's operating certificate. Table 30 shows the total number of captains, first officers, and flight engineers by air carrier group. The initial fatigue training cost for 2013 is based on the cost of training these flightcrew members.

Table 30: Air Carrier Groups for NPRM Cost Analysis

Group		Aircraft Type with Most Block Hours	Part 121 Air Carriers	Part 121 Flightcrew Members
1	Large Cargo Carrier	Aircraft > 100 seats equivalent	26	10,125
2	Commercial Passenger Carrier	Aircraft > 100 seats	8	39,406
3	Low Cost Carrier	Aircraft > 100 seats	9	11,260
4	Regional Passenger Carrier	Aircraft 20 < seats < 100	30	20,980
5	Small Cargo Carrier	Aircraft < 100 seats equivalent	3	236
6	Small Passenger Carrier	Aircraft < 20 seats	4	281
7	Charter Passenger Carrier	Aircraft > 100 seats	12	1,230
Total			92	83,518

Source: FAA OPSS, October 2009

Initial fatigue training is five hours. Every flightcrew member will be required to undergo initial fatigue training in 2013. In subsequent years, newly qualified flightcrew members will be required to undergo initial fatigue training, in addition to previously qualified flightcrew members that change employers. The annual retirement rate for flightcrew members is 3.3 percent. It is assumed that an equivalent number of flightcrew members will be qualified to replace those that retire. The "churn" rate (the share of flightcrew members that change employers within a given year) is one percent.

After undergoing initial fatigue training, each flightcrew member will be required to complete two hours of recurring training every year. This training will also be incorporated into existing distance learning programs.

The total number of flightcrew members for each year from 2013 to 2022 is assumed to be equivalent to the total number of flightcrew members holding certificates in October 2009, as recorded by OPSS. Table 31 shows the annual number of flightcrew members required to undergo both initial and recurring fatigue training from 2013 to 2022.

Table 31: Flightcrew Members in Fatigue Training

Year	Initial Training	Recurring Training	Total
2013	83,518	0	83,518
2014	3,591	79,927	83,518
2015	3,591	79,927	83,518
2016	3,591	79,927	83,518
2017	3,591	79,927	83,518
2018	3,591	79,927	83,518
2019	3,591	79,927	83,518
2020	3,591	79,927	83,518
2021	3,591	79,927	83,518
2022	3,591	79,927	83,518

The average hourly salaries of flightcrew members were then determined based on carrier-specific annual salary data from AIR, Inc. The salary data was then converted into an average hourly salary. The average hourly salary was calculated by dividing the average annual salary by the minimum guaranteed pay credit hours per month as defined in pilot labor agreements. The average hourly salaries were updated to 2009 values using the Air Transport Association (ATA) Passenger Cost Index. The labor component of the cost index was used to update the salaries from Q3 2006 to Q3 2009.

Flightcrew member fatigue training costs are equal to the number of flightcrew member training hours multiplied by the average hourly salary. Table 32 presents the nominal annual costs of fatigue training for flightcrew members. The total nominal cost over the ten-year period is $234.2 million. Table 33 presents the present value annual costs of fatigue training for flightcrew members. The total present value cost over the ten-year period is $149.3 million.

Table 32: Flightcrew Member Fatigue Training Nominal Annual Costs

Year	Initial Cost (millions)	Recurrent Cost (millions)	Total Cost (millions)
2013	$ 48.5	$ 0.0	$ 48.5
2014	$ 2.1	$ 18.6	$ 20.6
2015	$ 2.1	$ 18.6	$ 20.6
2016	$ 2.1	$ 18.6	$ 20.6
2017	$ 2.1	$ 18.6	$ 20.6
2018	$ 2.1	$ 18.6	$ 20.6
2019	$ 2.1	$ 18.6	$ 20.6
2020	$ 2.1	$ 18.6	$ 20.6
2021	$ 2.1	$ 18.6	$ 20.6
2022	$ 2.1	$ 18.6	$ 20.6
Total	**$ 67.2**	**$ 167.0**	**$ 234.2**

Table 33: Flightcrew Member Fatigue Training Present Value Annual Cost

Year	Initial Cost (millions)	Recurrent Cost (millions)	Total Cost (millions)
2013	$ 39.6	$ 0.0	$ 39.6
2014	$ 1.6	$ 14.2	$ 15.7
2015	$ 1.5	$ 13.2	$ 14.7
2016	$ 1.4	$ 12.4	$ 13.8
2017	$ 1.3	$ 11.6	$ 12.9
2018	$ 1.2	$ 10.8	$ 12.0
2019	$ 1.1	$ 10.1	$ 11.2
2020	$ 1.1	$ 9.4	$ 10.5
2021	$ 1.0	$ 8.8	$ 9.8
2022	$ 0.9	$ 8.2	$ 9.2
Total	**$ 50.6**	**$ 98.7**	**$ 149.3**

Fatigue Training – Dispatchers and Management

The proposed rule also requires that dispatchers and upper management having operational control over pilots be given fatigue training. The number of dispatchers in the U.S. air transport industry is equal to approximately three percent of the number of pilots. The number of management personnel is estimated to be three times the number of dispatchers. Therefore, the total number of dispatchers and management personnel required to receive fatigue training is estimated to be 12 percent of total flightcrew members. The corresponding increase in cost is assumed to be 12 percent.

The estimated total net present value cost of the proposed fatigue training requirements for dispatchers and management personnel over the ten-year period from

2013 to 2022 is $17.9 million. Table 34 lists both nominal and present value fatigue training annual costs for dispatchers and management.

Table 34: Dispatcher and Management Fatigue Training Costs

Year	Nominal Cost (millions)	PV Cost (millions)
2013	$ 5.8	$ 4.7
2014	$ 2.5	$ 1.9
2015	$ 2.5	$ 1.8
2016	$ 2.5	$ 1.7
2017	$ 2.5	$ 1.5
2018	$ 2.5	$ 1.4
2019	$ 2.5	$ 1.3
2020	$ 2.5	$ 1.3
2021	$ 2.5	$ 1.2
2022	$ 2.5	$ 1.1
Total	**$ 28.1**	**$ 17.9**

Fatigue Training - Summary

The estimated total net present value cost of the proposed fatigue training requirements for flightcrew members, dispatchers, and management personnel over the ten-year period from 2013 to 2022 is $167.2 million. Table 35 lists both nominal and present value fatigue training annual costs.

Table 35: Total Fatigue Training Costs

Year	Nominal Cost (millions)	PV Cost (millions)
2013	$ 54.3	$ 44.3
2014	$ 23.1	$ 17.6
2015	$ 23.1	$ 16.5
2016	$ 23.1	$ 15.4
2017	$ 23.1	$ 14.4
2018	$ 23.1	$ 13.5
2019	$ 23.1	$ 12.6
2020	$ 23.1	$ 11.7
2021	$ 23.1	$ 11.0
2022	$ 23.1	$ 10.3
Total	**$ 262.3**	**$ 167.2**

Rest Facilities – Overview

The proposed rule establishes maximum flight duty time limits for augmented operations that are dependent on the start time of the flight duty period, the number of crew assigned to the flight, and the class of rest facility installed on the aircraft. There are two types of costs associated with the rest facility cost component of the proposed rule. First, there is the cost resulting from the physical installation of the rest facilities in the aircraft fleet. Second, there is the loss of passenger revenue when the use of the rest facility removes seats from passenger revenue service. Table 36 provides an overview of the ten-year costs of the rest facility component of the proposed rule.

Table 36: Rest Facility Cost Overview

Cost Area	Nominal Cost (millions)	PV Cost (millions)
Installation	$ 49.8	$ 40.7
Lost Passenger Revenue	$ 176.8	$ 108.5
Total Rest Facilities	**$ 226.6**	**$ 149.1**

The proposed rule establishes detailed specifications for each of the three classes of rest facilities. Class 1 rest facilities are most conducive to reducing the risk of fatigue in augmented operations; accordingly, the maximum flight duty time permitted for augmented operations conducted with Class 1 rest facility-equipped aircraft is greater than the maximum flight duty time permitted for augmented operations conducted with either Class 2 or 3 rest facility-equipped aircraft. The definitions of the rest facilities are as follows:

- A Class 1 rest facility is a bunk or other surface that allows for a flat sleeping position and is located separate from both the flight deck and passenger cabin in an area that is temperature-controlled, allows the crewmember to control light, and provides isolation from noise and disturbance.
- A Class 2 rest facility is a seat in an aircraft cabin that allows for a flat or near flat sleeping position; is separated from passengers by a minimum of a curtain to provide darkness and some sound mitigation; and is reasonably free from disturbance by passengers or crewmembers.

- A Class 3 rest facility is a seat in an aircraft cabin or flight deck that reclines at least 40 degrees and provides leg and foot support.

Rest Facilities – Installation

There are three cost categories associated with the installation of rest facilities. First, there are one-time, non-recurring, design costs. These consist of system, development, engineering, analysis, and certification costs. Second, there are "kit" equipment costs for the hardware required for each installation. Third, there is the cost of the labor required for rest facility installation.

The FAA obtained detailed cost estimates from two supplemental type certificate (STC) holders. Their estimates indicate that Class 1 facilities are much higher in cost relative to Class 2 and 3 facilities, which are roughly equivalent. For the purposes of this analysis, FAA averaged the cost estimates from the two STC holders and summarized the costs into a per-installation cost. Table 37 presents the cost per installation used for this analysis.

Table 37: Cost per Rest Facility Installation

Rest Facility Class	Cost per Installation
Class 1	$259,000 - $1,500,000
Class 2	$46,000
Class 3	$31,000

In order to estimate the total cost of on board rest facilities, the FAA multiplied the unit costs by the number of aircraft that could be affected by the rule (defined as aircraft that operate long range). FAA believes that in the long term it is more cost effective for carriers to install rest facilities than to add pilots to the flightcrew. FAA believes that no Class 2 or Class 3 rest facility will need to be added or upgraded on any of the aircraft currently used in international transportation because existing business or first class seats meet the requirements as Class 2 or Class 3 rest facilities.

Rest facilities will need to be installed or upgraded on 104 aircraft used in international service. Installation will be completed by the end of 2013. Nineteen of these aircraft will have bunks installed at $1.5 million per aircraft and the remaining 85 aircraft will have the single bunk facility upgraded to a double bunk facility at $250,000 per aircraft. The total estimated cost is $49.8 million ($40.7 million present value). This cost estimate does not include any weight penalty costs. The FAA solicits public input regarding the weight penalty costs.

Rest Facilities - Loss of Passenger Revenue

There will be some passenger revenue loss associated with the use of rest facilities in augmented operations. The FAA found that it is always cheaper to use a higher level rest facility than to add a flightcrew member. As discussed in the previous section, Class 1 rest facilities will be installed in locations so that there is no impact on passenger revenue. Existing business and first class seats meet the criteria to serve as Class 2 and Class 3 rest facilities. Currently, most carriers assign flightcrew members to rest in coach seats during augmented operations. The proposed rule will result in the loss of passenger revenue because carriers will need to assign flightcrew members to rest in Class 2 or 3 rest facilities (i.e. business/first class seats) rather than cheaper coach seats. The loss of passenger revenue is thus equal to the fare difference between business/first class seats and coach seats.

FAA analyzed one year of actual flights to determine the categories and total number of aircraft and flights affected. We multiply the estimated number of affected flights by the revenue lost when Class 2 or Class 3 rest facilities are used. The weighted average additional incremental loss for a Class 2 rest facility[26] is $2,034 and the weighted average cost for a Class 3 rest facility[27] is $5,084. We multiply the estimated number of annual flights by the appropriate estimated cost of the revenue lost. The total cost would be $17.7 million.

Table 38 shows the estimated annual operations for the most cost effective solutions based upon the proposed constraints, equipment, and number of pilots. The FAA has analyzed the duty matrix and evaluated it in terms of the additional costs per pilot[28] versus the costs of additional facilities and estimates that in the long run it would always be less costly to provide rest facilities rather than to add a pilot.[29] Our analysis assumes that there are always three pilots available per flight and that carriers attempt to minimize the potential flightcrew costs. For the flights that are 15.5 hours or more, a

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[26] Weighted average price difference between coach and business class

[27] Weighted average price difference between coach and estimated first class

[28] To estimate the hourly pilot cost of $625, we divide the approximate annual burdened pilot cost of $300,000 by the estimated hours flown per year of 480 (40 hours per month times 12 months per year).

[29] Once the flight time exceeds 14 hours, additional crew would be required.

Class 1 rest facility would be required, which would not result in any passenger revenue loss.

Table 38: Estimated Annual Operations for the Most Cost Effective Solutions

Duty Period Start Time	Class 2 Rest Facility			Duty Time			Total
	Annual Operations	Passenger Revenue Loss per Operation	Nominal Annual Cost	Annual Operations	Passenger Revenue Loss per Operation	Nominal Annual Cost	Nominal Annual Cost
0000-0559	157	$5,084	**$797,082**	144	$2,034	**$293,453**	**$1,090,535**
0600-0659	0	$5,084	**$0**	0	$2,034	**$0**	**$0**
0700-1259	835	$5,084	**$4,247,137**	760	$2,034	**$1,544,990**	**$5,792,127**
1300-1659	947	$5,084	**$4,814,215**	1,259	$2,034	**$2,560,179**	**$7,374,394**
1700-2359	550	$5,084	**$2,795,734**	309	$2,034	**$628,148**	**$3,423,882**
Total	**2,489**	**$5,084**	**$12,654,167**	**2,472**	**$2,034**	**$5,026,770**	**$17,680,937**

Rest Facilities – Summary

The installation and upgrade of aircraft rest facilities and the lost passenger revenue resulting from the use of the rest facilities results in a ten-year nominal cost of $226.6 million ($149.1 million present value.) Table 39 presents the annual nominal and present value costs of the rest facility component of the proposed rule.

Table 39: Rest Facilities Cost Summary

Year	Nominal Cost (millions)	PV Cost (millions)
2013	$ 67.5	$ 55.1
2014	$ 17.7	$ 13.5
2015	$ 17.7	$ 12.6
2016	$ 17.7	$ 11.8
2017	$ 17.7	$ 11.0
2018	$ 17.7	$ 10.3
2019	$ 17.7	$ 9.6
2020	$ 17.7	$ 9.0
2021	$ 17.7	$ 8.4
2022	$ 17.7	$ 7.9
Total	**$ 226.6**	**$ 149.1**

Summary of Benefits and Costs

Following NTSB recommendations regarding pilot fatigue, labor and industry worked together to provide the basis of this rulemaking. Furthermore, Congress has directed the FAA to issue a rule addressing pilot fatigue. We have validated the need for this rule in the benefit discussion. Based on the expected effectiveness of this proposed rule at preventing fatigue accidents with an averted fatality valued at $6 million, the simulation methodology produced benefits of $659.4 million with $463.8 million in present value. The total estimated costs of the proposed rule over 10 years are $1.25 billion ($804 million at present value). There is over a 7 percent probability that undiscounted cost of avertable passenger airplane accidents would exceed $1.25 billion and over a 10 percent probability the present value of the cost of avertable passenger airplane accidents would exceed $796 million. The benefits from a near term catastrophic accident in a 150-passenger airplane with average load factor exceeds the cost of this rule. If the value of an averted fatality were increased to $12.6 million, the present value of the benefits would equal the present value of compliance costs.

In addition, the FAA has identified two additional areas of unquantified benefits: preventing minor aircraft damage on the ground, and the value of well rested pilots as accident preventors and mitigators. Due to data limitations, the FAA was unable to estimate the cumulative effect of preventing minor aircraft damage on the ground, but if the rule were to reduce damage by about $600 million over 10 years ($340 million present value) it would break even in terms of net benefits. These considerations lend weight towards moving ahead with this proposal. FAA invites comment on this issue.

Appendix A

Pilot Deviations and Accidents by Duty Hours

a. Pilot Deviations

Between 1987 and the present, there were 686 records of pilot deviations in part 121 operations that contain information on pilot duty time in the 24 hours preceding the deviation (cases where equipment failure was listed for the deviation were excluded from the data set). Table A-1 and Figure A-1 below show the frequency of pilot deviations in relation to duty time.

As part of the analysis for this rulemaking, the FAA obtained data on pilot work patterns from ten carriers covering one month of flight activity during 1999.[30] These data were used to create profiles of the work patterns of the pilot population. Data for nine carriers were provided by pilot labor unions. The FAA also obtained data on actual pilot use from one major part 121 air carrier that was added to data from the other carriers.[31]

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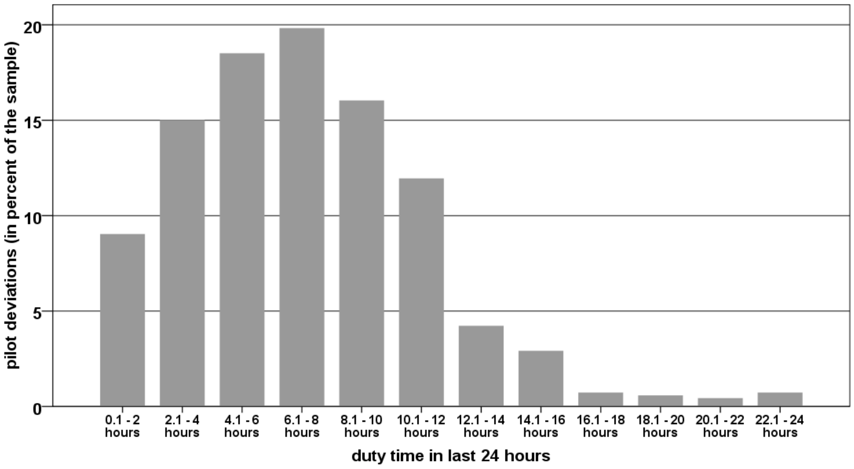
[30] *Ibid.*

[31] FAA has also received more recent data on pilot work patterns from six carriers, covering two months of actual flight activity during 2009 for each carrier. These data on flight crew exposure to risk are currently being characterized and analyzed by FAA, and these data have not yet been organized around the "for each duty hour, how many duty hours have occurred in the prior 24 hours?" parameter. For this reason, the comparisons to occurrences of pilot deviations and accidents are made to the 1999 pilot work activity data.

Table A-1. Distribution of Pilot Deviations by Duty Hours

Duty Time in the Last 24 hours	**Pilot Deviations**	**Percent**	**Cumulative Percent**
0 – 2 hours	62	9.0	9.0
2 – 4 hours	103	15.0	24.0
4 – 6 hours	127	18.5	42.5
6 – 8 hours	136	19.8	62.3
8 – 10 hours	110	16.0	78.3
10 – 12 hours	82	12.0	90.3
13 – 14 hours	29	4.2	94.5
15 – 16 hours	20	2.9	97.4
16 + hours	17	2.5	99.9
Total	***686***	***99.9***	

Figure A-1. Distribution of Pilot Deviations by Duty Hours



The data was converted into one record for each pilot with a scheduled (or for one carrier, an actual) line of flying for the month. Each pilot record tracked a pilot's activity for every hour in the entire month. The beginning and end of each trip segment were recorded for each pilot and put into a database. Parameters of interest were then calculated such as the length of duty periods, flight time and duty time per day or in the last 24 hours, rest time, and the numbers of takeoffs and landings. The analysis tracked these activities in local time as well as base time (defined as the time at the location where the pilot began a multi-day trip).

Although some carriers provided data for both captains and first officers, other carriers provided data for captains only. The study used data only for captains in the accident analysis to prevent weighing one carrier's responses more heavily than another in measuring exposure. The FAA found there were differences between the two sets of data in some work schedule parameters examined.

Table A-2. Distribution of Pilot Duty Time in Prior 24 Hours and Pilot Deviations

Figure Pilot Duty

A-2. Prior Time

Hours	Captain's Hours	Duty Time Percentage	Pilot Deviations	Deviations Percentage
0 to 2	284,128	23%	316	9%
2 to 4	279,531	22%	427	12%
4 to 6	261,051	21%	597	17%
6 to 8	212,764	17%	686	20%
8 to 10	138,749	11%	644	19%
10 to 12	64,147	5%	476	14%
12 to 14	14,798	1%	218	6%
14 or more	1,176	<1%	106	3%
Total	1,256,344		3,470	

Exposure v Pilot Deviations

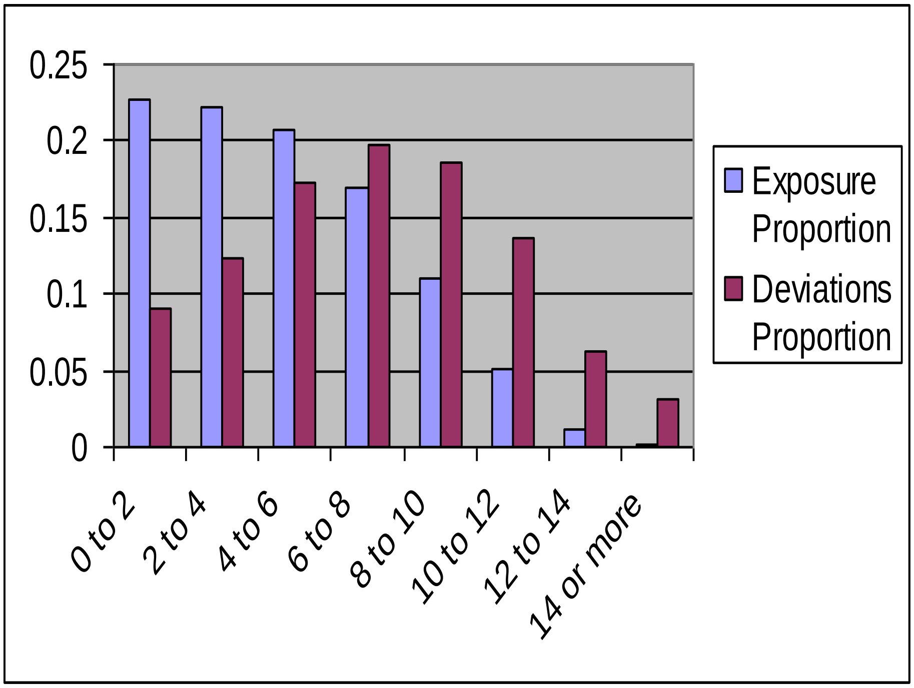
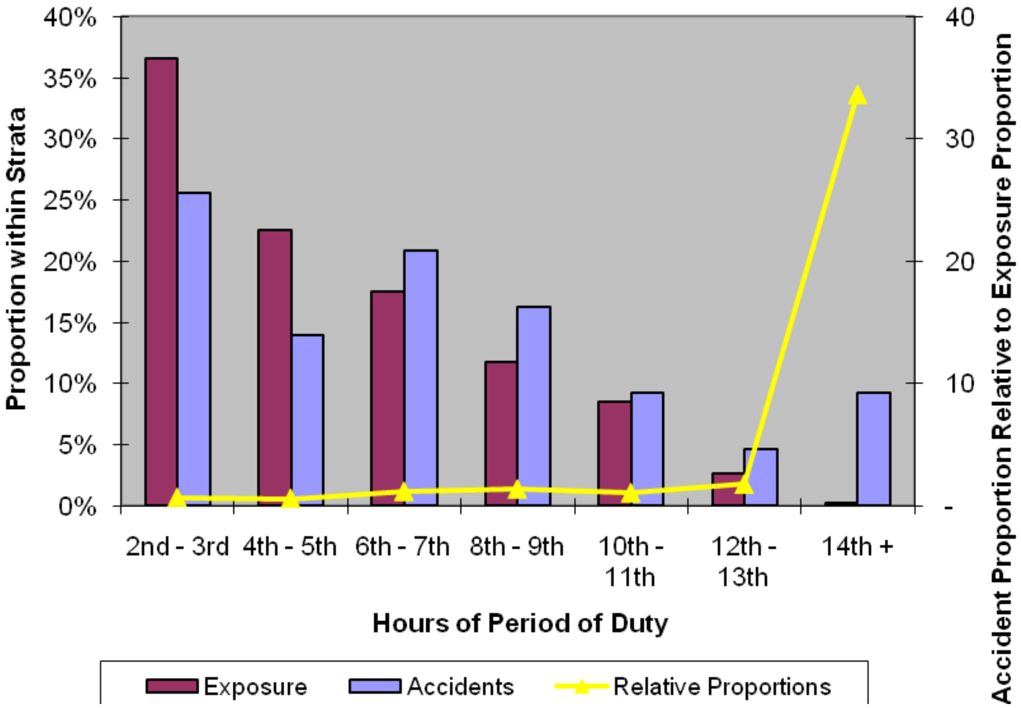
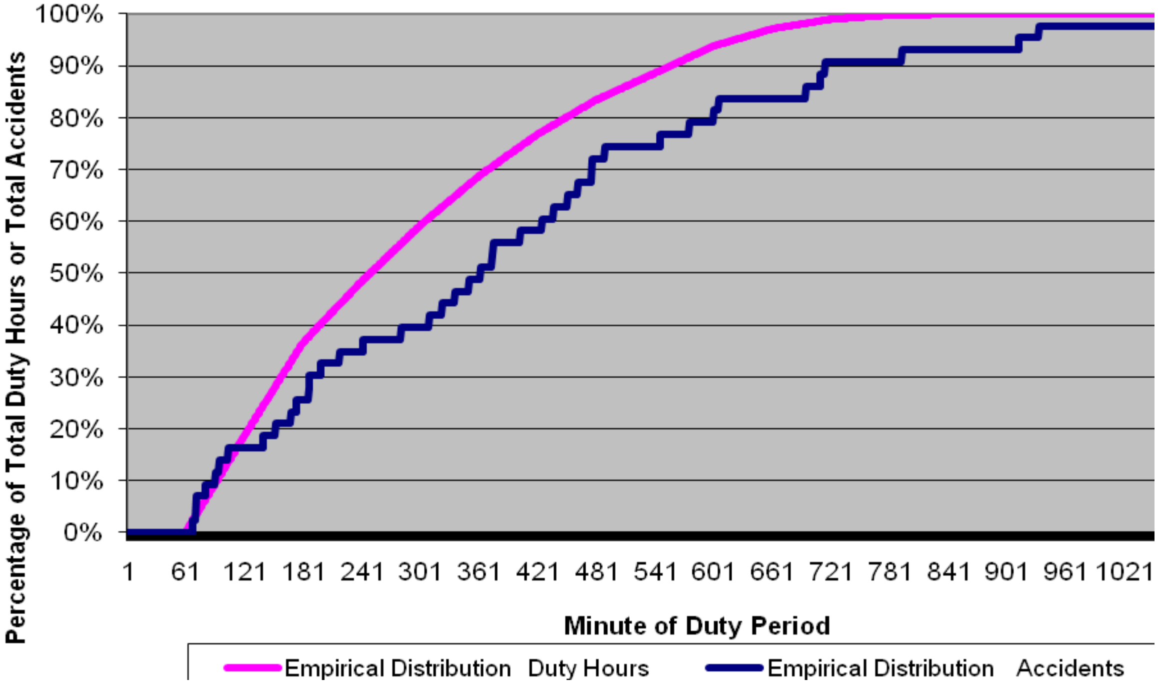


Table A-2 and Figure A-2 suggest that pilot deviations are less likely to occur when a pilot has less than 6 hours of duty time during the past 24 hours than if the pilot has more than 6 hours of duty time during the past 24 hours. Moreover, pilot deviations after 6 hours of duty time are much higher than one would expect given exposure. This finding is consistent with the above fatigue science findings.


Captains' Duty Hours and Accidents by Length of Duty Period with 1990-2009 Accident Data


Kolmogorov-Smirnoff Comparison, Starting at Minute 61 of Duty Period with 30% Mid-Duty Day Adjustment 43 Accidents 1990 - 2009

Appendix B

Statistical Tests of Relationship between Length of Duty Time and Accidents

The Flight Crewmember Duty and Rest Requirements NPRM accident analysis for the United States air transportation industry is based on statistical comparison of domestic flight crew duty data from six operators, based on their flight crews' actual activity during a spring and summer month of 2009. Two statistical testing methods were used to examine the distribution of pilot duty hours and the distribution of duty hour features of accident histories. The statistical comparisons were made for the hour within a pilot duty period that a accident occurs.[32] If the

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[32] To illustrate, suppose the total available pilot duty data are comprised of two pilots, one of whom serves a duty period that is seven hours in length, and the second of whom serves a duty period of nine hours in length. In this case, the data set characterizing pilot duty by hour in duty period contains two hours of duty in the first hour of the duty period, two hours of duty in the second hour of the duty period, and so forth, culminating in two hours of duty in the seventh hour of the duty period, one hour of duty in the eight hour of the duty period, and one hour of duty in the ninth hour of the duty period. If, to continue the example, one of the pilots experiences an occurrence of interest in the seventh hour of her duty period, then the data set for "occurrences of interest" would contain one instance, taking place in the seventh hour of the duty period.

likelihood of a human factors accident occurring is the same for all hours within a duty period, then the distribution of accident occurrence by the hour within a duty period should not be significantly different from the distribution of pilot duty hours by hour within the duty period, and the relative frequency of the occurrence of such accidents would be expected to resemble the relative frequency of hours within pilot duty periods. The purpose of the statistical tests is to compare these two distributions and assess their similarity to or dissimilarity from one another using accepted statistical tools.

There are 43 accidents in the data set. They include accidents involving FAR part 121 operators that resulted in significant aircraft damage, serious injury to passengers or worse outcomes, and occurred between 1990 and 2009. They are accidents for which mechanical failures were not causal and in which human factors issues involving the flight crews were pertinent. NTSB investigations and reports on some of these accidents cited “fatigue” or pilot rest and duty issues as relevant to the accident**.** The purpose of the statistical analysis is to examine the relationship if any between human factor accidents and duty patterns, the accident data set also includes human factors accidents for which no citation of “fatigue” or similar factors was made.

Duty period characteristics from the accident pilot histories are then categorized in a comparable way, with a count of all accidents in the data set that occurred in the first or second hour of the pilot’s duty period, the third or fourth hour of the pilots duty period, and so forth. This initial data set for 2009 pilot work patterns and accident incidence is reported in Table B-1.

Table B-1. Pilot Duty and Accident Incidence **by Hour in Duty Period**

Hour Block	Exposure Duty Hrs	Percentage of Duty Hrs	Accidents	Percentage of Accidents
0 to 1	195,691	13.34%	0	0.00%
1 to 2	192,786	13.14%	7	16.28%
2 to 3	187,372	12.77%	4	9.30%
3 to 4	175,247	11.95%	4	9.30%
4 to 5	160,567	10.95%	2	4.65%
5 to 6	141,538	9.65%	4	9.30%
6 to 7	119,601	8.15%	5	11.63%
7 to 8	98,501	6.71%	6	13.96%
8 to 9	76,547	5.22%	1	2.33%
9 to 10	54,501	3.72%	2	4.65%
10 to 11	34,533	2.35%	1	2.33%
11 to 12	19,078	1.30%	1	2.33%
12 to 13	8,143	0.56%	1	2.33%
13 to 14	1,867	0.13%	2	4.65%
14 to 15	631	0.04%	0	0.00%
15 to 16	238	0.02%	2	4.65%
16 to 17	93	0.01%	0	0.00%
17 to 18	41	0.00%	1	2.33%
Total	1,466,975		43	

While hour by hour duty period characteristics represent a sensible approach to identifying pilot exposure to human factors accident risk, some adjustment to these data is necessary for a valid comparison, since in some cases specific duty hours (or percentages of duty hours) can be shown to be unrelated to the possibility of aviation accident or mishap. For this analysis, two specific adjustments are considered.

First, it is nearly always the case that the first hour of a pilot's duty day involves check-in and information gathering that takes place on the ground, prior to the first take off of the day. Naturally enough, every duty period has a first hour, and as can be seen in Table 1 above, the first hour makes up a significant percentage of total pilot duty hours, even though no flight activity occurs during it. For this reason, in the following statistical tests the first hour of pilot duty periods is omitted from consideration.

Second, once pilots have completed their first flight segment of the day (which lasts varying amounts of time depending on flight distance, itinerary, etc.), during any given hour of pilot duty periods, some percentage of pilots are on the ground between flight segments and involved in post-flight or pre-flight activities. Average flight segment lengths vary by airline and by airline business model, so it is not possible to develop specific modeling approaches to this issue.

In the pilot exposure data made available by airlines for this analysis, out of 1,271,284 total duty hours served (a total which excludes duty hours that are the pilot's first duty hour of the day), there are 985,566 flight hours. This suggests that about 77 per cent of duty hours actually involve accident risks stemming from flight activity, and that some adjustment to the distribution of duty hours counted over the duty period would be appropriate for accurately reflecting exposure to human factors accident risk. Since duty hours begin to fall off significantly after the eighth hour of duty, as shown in Table B-1 above, and since once the final hours of a duty period are reached it is more likely that the pilot is in flight and performing his or her final segment of the duty day, this adjustment in the exposure data is accomplished by reducing the duty hours reported between the third and eighth duty hours of the duty period by 30 percent. The effect of this adjustment to exposure risk is illustrated in Table B-2, which updates the "raw" exposure data from Table B-1.

Table B-2. "Risk Adjusted" Pilot Duty and Accident Incidence by Hour in Duty Period

Hour Block	Exposure Duty Hrs	Percentage of Duty Hrs	Accidents	Percentage of Accidents
0 to 1	***n/a***			
1 to 2	192,786	13.14%	7	16.28%

2 to 3	187,372	12.77%	4	9.30%
3 to 4	***122,673***	8.36%	4	9.30%
4 to 5	***112,673***	7.66%	2	4.65%
5 to 6	***99,077***	6.75%	4	9.30%
6 to 7	***83,721***	5.71%	5	11.63%
7 to 8	***68,951***	4.70%	6	13.96%
8 to 9	***53,583***	3.65%	1	2.33%
9 to 10	54,501	3.72%	3	6.98%
10 to 11	34,533	2.35%	1	2.33%
11 to 12	19,078	1.30%	1	2.33%
12 to 13	8,143	0.56%	1	2.33%
13 to 14	1,867	0.13%	1	2.33%
14 to 15	631	0.04%	0	0.00%
15 to 16	238	0.02%	2	4.65%
16 to 17	93	0.01%	0	0.00%
17 to 18	41	0.00%	1	2.33%
Total	1,039,684		43	

The Pearson's Chi Squared "goodness of fit" test[33] is a frequent approach to testing whether these two distributions – expressed as histograms reporting the percentage of each variable within each two hour time bucket – have a statistically significant difference. If there is no statistically significant difference between the two distributions, there is limited evidence to

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[33] A description of the Chi Square goodness of fit test can be found in any introductory statistics text. A comprehensive discussion of the test, with references, can be found online at http://en.wikipedia.org/wiki/Pearson's_chi-square_test

support a claim that accident likelihood changes with changes in duty hour. An interpretation of this outcome is that the risk of accident does not vary with duty time. Thus, for the statistical test, the null hypothesis is that there is not a statistically significant difference between the two distributions.

To conduct the Chi Squared test, pilot duty hours from the exposure data set (disregarding the first hour of each pilot duty period) are divided into distinct categories of two hours in length: duty hours that occurred in the second or third hour of a duty period**,** duty hours that occurred in the fourth or fifth hour of a duty period, and so forth, with the final bucket made up of duty hours that occurred in the 14th or greater hour of a duty period.

The test statistic is taken from a Chi Squared distribution with n-1 degrees of freedom, where n is the number of histograms used in the comparison of exposure and accident data. In this case there are seven degrees of freedom for the text. Table 3 reports these test results and the critical values for the Chi Squared test at the 5% and 10% significance levels. The calculated Chi Squared test value of 131.5 exceeds these critical values, indicating that the distribution of exposure hours and the distribution of accident incidence within duty periods are not the same, although it is important to recognize that this outcome is driven largely by the comparison between exposure hours in the 14th and greater hours of pilot duty periods and the frequency of accidents occurring during those later hours of pilot duty periods.

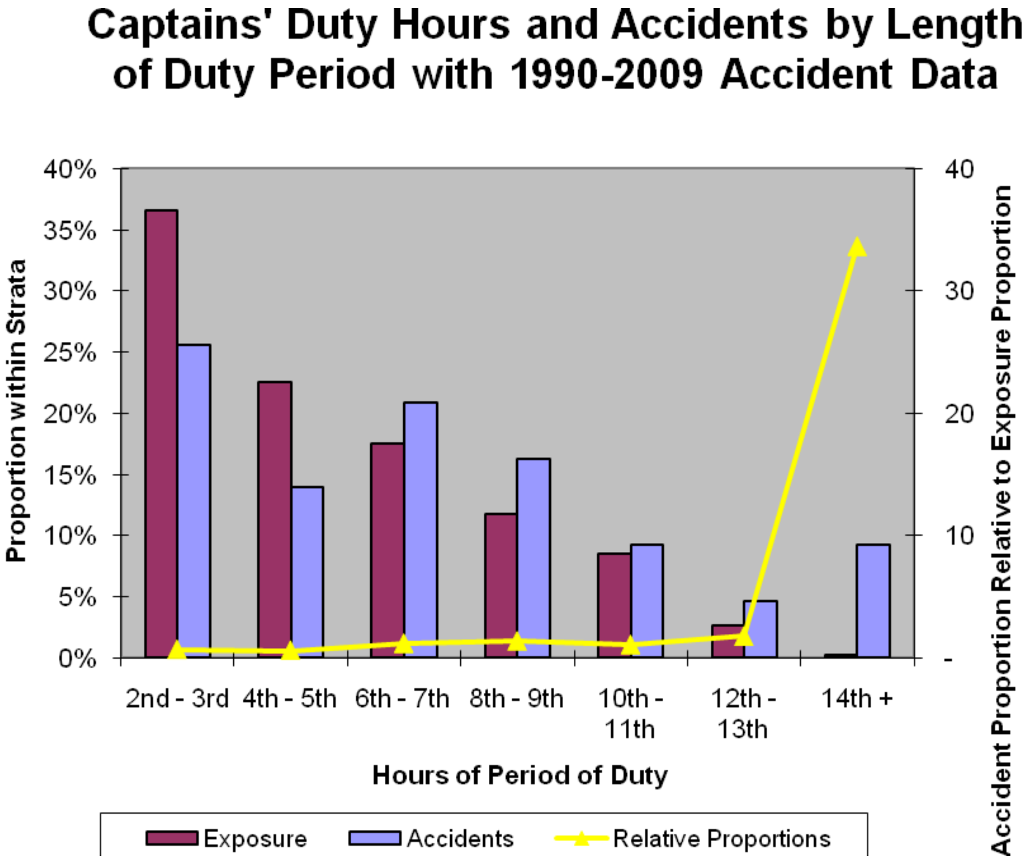
Table B-3. Chi Squared Results for Comparing Time in Duty Period Exposure and Accident Characteristics

Hour in Duty Period	Pilot's Hours	Exposure Proportion	Accidents	Accident Proportion	Relative Proportion
2nd & 3rd	380,158	0.37	11	0.26	0.70
4th & 5th	235,070	0.23	7	0.16	0.72
6th & 7th	182,797	0.18	9	0.21	1.19
8th & 9th	122,534	0.12	7	0.14	1.18
10th & 11th	89,034	0.09	4	0.09	1.09
12th & 13th	27,221	0.03	2	0.05	1.78
14th +	2,870	0.00	4	0.09	36.70
Total	***1,039,684***		***43***		

	Calculated Chi^2:	***131.5***		***10% Chi^2:***	***10.6***
	Degrees of Freedom:	***6***		***5% Chi^2:***	***12.6***

The data underlying the Chi Squared comparison is shown graphically in Figure B-1. below.

Figure B-1. Pilot Duty Hours and Accidents by Hour in Duty Period – Accidents 1990 to 2009



A second statistical test was also used to assess the significance, if any, of differences between the distribution of pilot duty hours observed in the 2009 exposure data and the distribution of the set of human factors accidents by the time at which the accidents occurred in the pilot's duty period. This test, which is also used to examine the similarity of distributions, is the two sample Kolmogorov-Smirnov test (henceforth, K-S test), which is used to test whether two samples can be regarded as samples from a single distribution.[34]

The K-S test is performed by expressing the exposure data and accident data as two separate cumulative distribution functions, each running from 0 to 100 per cent. To make this comparison, some adjustment of the data sets being compared is made.

Because data on accident time (that is, time within a duty period) exists at the hour and minute level, the exposure data is converted from hourly to "by minute" data by dividing the percentage share of duty hours within an hour block by 60. Consider a simple example where duty periods last 1 or 2 hours, and of 100 total duty hours, 60 are in the first hour block (from 0 to 1 hours) and 40 are in the second hour block (from 1 to 2 hours). In this case, 60 percent of duty hours are within the first hour block, and 40 percent are within the second hour block. To convert this exposure profile from an hour basis to a minute basis, these percentages are divided by 60 (minutes per hour). Thus, each minute within the first hour block represents one percent of the total minutes contained by the 100 duty hours, and each minute within the second hour block represents 0.667 percent contained by the 100 total duty hours.

Table B-4 presents the "risk adjusted" distribution of duty hours that is shown in TableB-2 above along with the "percentage of duty minutes within each duty hour" calculation described above. In the 2009 exposure dataset for duty hours, about 13.1 percent of observed duty hours occur in someone's second hour within a duty period (when first flights of the day commence and exposure to risk begins, as discussed above), and if this percentage share is subdivided into minutes, each of the 60 minutes with this second duty hour represents about 0.219% of all duty minutes over the 17 hour span between the second hour and the 18th. The reported exposure data also includes the reduction by 30 per cent of duty hours between the third and ninth hours in duty periods, to reflect the fact that during the middle portions of the duty day, some percentage of pilots are on the ground between flights. They are actively engaged in their duties during these times, but they are not at risk of an in flight accident.

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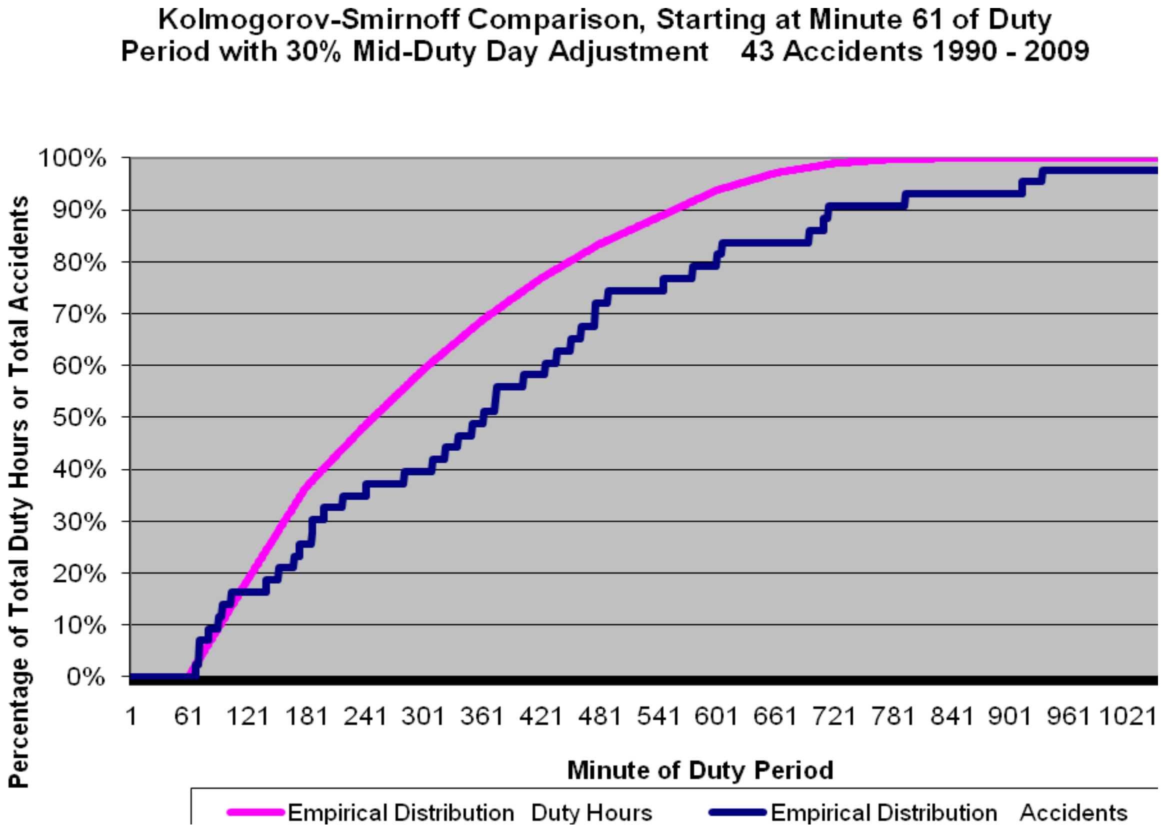
[34] A description of the Kolmogorov-Smirnov test can be found in more advanced statistics texts. A comprehensive discussion of the test, with references, can be found online at http://en.wikipedia.org/wiki/Kolmogorov-Smirnov_test

Table B-4. Percentage Distribution of Duty Hours and Minutes, Domestic Pilot "Hour in Duty Period" Exposure Set

Hour Block	Exposure Duty Hrs	Percentage of Duty Hrs	Percentage per Duty Min	Accidents	Percentage of Accidents
0 to 1	n/a				
1 to 2	192,786	13.14%	0.2190%	7	16.28%
2 to 3	187,372	12.77%	0.2129%	4	9.30%
3 to 4	122,673	8.36%	0.1394%	4	9.30%
4 to 5	112,397	7.66%	0.1277%	2	4.65%
5 to 6	99,077	6.75%	0.1126%	4	9.30%
6 to 7	83,721	5.71%	0.0951%	5	11.63%
7 to 8	68,951	4.70%	0.0783%	6	13.96%
8 to 9	53,583	3.65%	0.0609%	1	2.33%
9 to 10	54,501	3.72%	0.0619%	3	6.98%
10 to 11	34,533	2.35%	0.0392%	1	2.33%
11 to 12	19,078	1.30%	0.0217%	1	2.33%
12 to 13	8,143	0.56%	0.0093%	1	2.33%
13 to 14	1,867	0.13%	0.0021%	1	2.33%
14 to 15	631	0.04%	0.0007%	0	0.00%
15 to 16	238	0.02%	0.0003%	2	4.65%
16 to 17	93	0.01%	0.0001%	0	0.00%
17 to 18	41	0.00%	0.0000%	1	2.33%
Total	1,039,684			43	

Also shown in Table B-4 are 43 accidents, which took place between 1990 and 2009, for which adequate data exists for identifying when within a duty period the accident occurred. Thus, each accident represents 1/43, or 2.33 percent, of the total data set of accidents. These accidents occurred at duty times up to 17 and a half hours, so the comparison constructed for the K-S test procedure looks at exposure data periods up to 18 hours in length, although there are relatively very few of these extremely long duty periods in the exposure data. A graphical comparison of the cumulative duty minute distribution and the cumulative distribution of accidents by duty minute is shown in Figure B-2.

Figure B-2. Comparison of Exposure and Accident Cumulative Percentage Profiles



As shown in the figure, the two cumulative curves for exposure and accident duty times each rise to 100 percent, but do so along different paths or trajectories. The purpose of the K-S test (like that of the Chi Squared test) is to test whether the two curves can be regarded as representing samples from distinct probability distributions. In these tests, the statistical “null hypothesis” is that the two distributions of events (duty hours served as a measure of exposure to risk, and accidents by the hour within the duty period at which the accident occurred) are the same. If the statistical test (Chi Squared or K-S) results in the rejection of this null hypothesis at some level of significance, then with that level of confidence it can be asserted that exposure to risk is not summed up by relative numbers of hours within specific hours within the duty period, and that other factors, such as whether the duty hour at which an accident occurs is early or late in a duty period, also contribute to accident risk. If the two curves are distinct from one another at a statistically significant level, it could be concluded that a pilot's time within a duty period does influence the risk or likelihood of a human factors related accident occurring, and in this particular case, this risk increases with the duty time.

The testing procedure for the K-S test of significant difference between two curves involves measuring the distance between the curves at each point. The test statistic is the maximum of those distances, taken over the whole domain over which the two curves reach their terminal value of 100 percent. In the present example, the maximum value is 0.2107, which occurs at minute 309, where the cumulative percentage for the exposure data reaches 60.6 per cent and the cumulative percentage for the accident data reaches 39.5 per cent. (The point or minute at which the maximum distance between these cumulative percentage curves occurs is not relevant to the test result.) This distance is shown in Figure B-3.

Figure B-3. Test Statistic for Comparison of Exposure Duty Hour Curve and Accident Curve

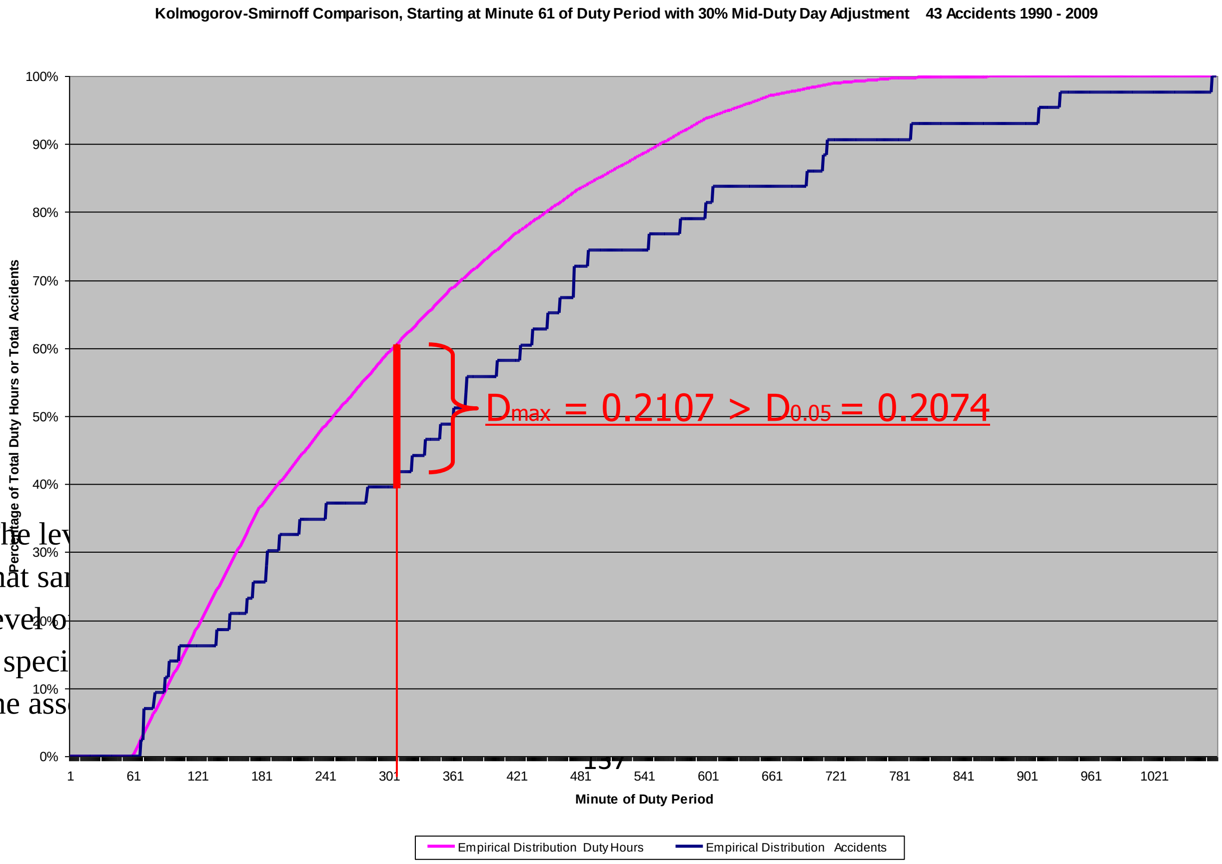


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Table B-3. Critical Values for K-S Testing (Sample Size of 43)

Level of Significance	K-S Test Factor	1/root(43)	K-S Test Critical Value	Test Statistic
0.20	1.07	0.152	0.1632	
0.15	1.14	0.152	0.1738	
0.10	1.22	0.152	0.1860	
0.05	1.36	0.152	0.2074	**0.2107**
0.01	1.63	0.152	0.2486	

Comparison of these critical values with the test statistic at the 0.05 significance level of 0.2074 indicates that at that level of significance, the difference between the cumulative curve of exposure times within duty periods and the cumulative curve of times within duty periods at which accidents occurred can be regarded as statistically significant. This can be interpreted as indicating that the frequency with which accidents from the recent past happened within specific hours within a duty period is not related simply to the proportion of duty hours that pilots serve within specific hours of their duty period, and that the risk of an accident is not uniform across all hours within duty periods. That is, with this level of significance, the hour of the duty period matters for accident risk.

Appendix C

Pilot Deviations by Time of Day

One way to study pilot deviations is examine how they vary throughout the day. Deviations represent multiple types of violations, ranging from serious runway incursions interfering with landings and takeoffs to simple airspace transgressions. Given their potential severity, they are recorded system-wide because they are all assumed to represent precursors to potential accidents. Each violation record contains multiple fields addressing the aircraft, the environment and the pilot involved in the incident. These incidents number in the thousands. These records provide a needed large sample to address the fatigue issue. In particular, pilot deviations carry several data fields considered related to pilot fatigue. They are: (a) duty time in the last 24 hours before the violation, (b) flight time in the past 24 hours before the violation, (c) leg time before the violation, (d) time of day, and (e) season of the year.

Pilot deviations are actions of the pilot which violate the Code of Federal Regulations (CFR), previously called Federal Aviation Regulation (FAR). Pilot deviations also take place when the North American Aerospace Defense Command (NORAD), Air Defense Identification Zone (ADIZ) tolerance is neglected. Starting with 1987, pilot deviations have been documented by air traffic and flight standards on FAA Form 8020-17, Preliminary Pilot Deviation Report, and FAA Form 8020-18, Investigation of Pilot Deviation Report. The results are then coded into the Pilot Deviation System (PDS) database. The FAA uses the PDS database to monitor the number of events, type of events (e.g., air deviations, surface deviations, or airspace violation) and the factors related to the events. The FAA issues one report for each pilot deviation regardless of the number of aircraft involved. The information in the database reflects a mix of preliminary and final reports. Pilot deviations require 90 days to stabilize due to reporting procedures, volume, and workload.

A large sample from the database ranging from 1987 to present was secured and analyzed in multiple ways. To focus strictly on fatigue as the key issue, records with the following conditions were removed from the analysis:

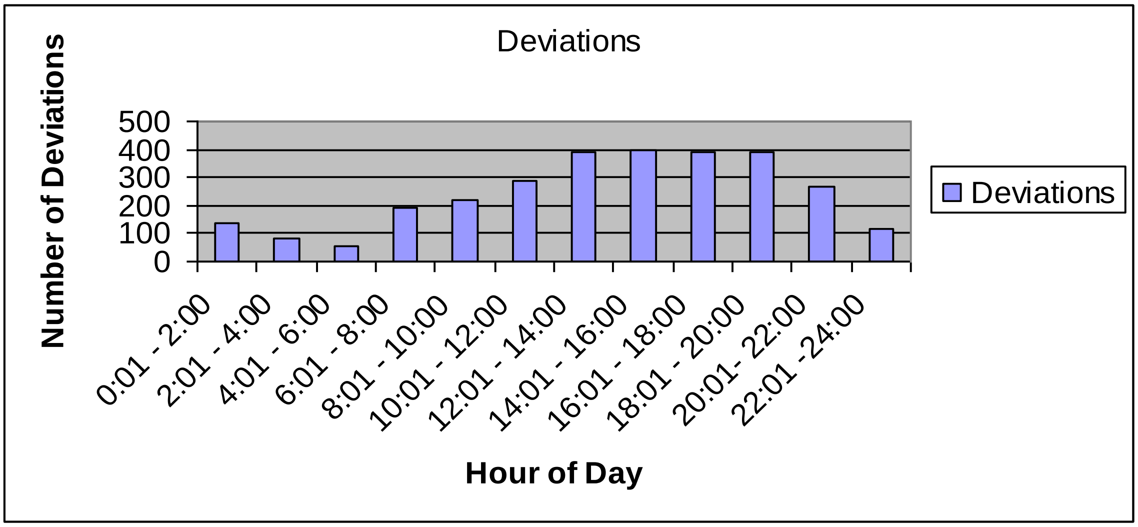
(a) improbable values, blanks, “zero” in the field of interest,
(b) non- Part 121 operations, and
(c) deviations caused by adverse weather or equipment failure, two causes not truly being pilot-related.

As can be seen in table C-1 and figure C-1 pilot deviations are more likely to occur in the afternoon than any other time of day. Also, there are few pilot deviations between 12:00 midnight and 6:00 am.

Table C-1. Distribution of deviations by local hour of the day.

Local hour of the day when deviation occurred	Pilot deviations	Percent	Cumulative Percent
0:01 – 2:00	137	4.5	4.7
2:01 – 4:00	80	2.6	7.4
4:01 – 6:00	57	1.9	9.4
6:01 – 8:00	193	6.4	16.0
8:01 – 10:00	218	7.2	23.4
10:01 – 12:00	286	9.4	33.2
12:01 – 14:00	392	12.9	46.6
14:01 – 16:00	398	13.1	60.2
16:01 – 18:00	387	12.8	73.4
18:01 – 20:00	391	12.9	86.8
20:01 – 22:00	269	8.9	96.0
22:01 – 24:00	117	3.9	100.0
Total	***2,925***		

Figure C-1. Distribution of deviations by local hour of the day.



The distribution of pilot deviations can be compared to the distribution of aircraft activity to see if pilot deviations are more than would be expected for any portion of the day. In this analysis the count of takeoffs and landings by time of day were used as a measure of aircraft activity. The results are presented in table C-2 and figure C-2.

Table C-2 Pilot Deviations and Take Off and Landing Operations By Time of Day

Hours	**Deviations**	**Percent**	**Operations**	**Percent**
0:01 - 2:00	137	4.7	468,610	2
2:01 - 4:00	80	2.7	240,000	1
4:01 - 6:00	57	1.9	441,659	1.9
6:01 - 8:00	193	6.6	2,094,083	8.9
8:01 - 10:00	218	7.5	2,594,592	11
10:01 - 12:00	286	9.8	2,788,547	11.8
12:01 - 14:00	392	13.4	2,784,202	11.8
14:01 - 16:00	398	13.6	2,772,942	11.8
16:01 - 18:00	387	13.2	2,917,272	12.4
18:01 - 20:00	391	13.4	2,829,391	12
20:01- 22:00	269	9.2	2,265,871	9.6
22:01 -24:00	117	4	1,384,053	5.9
Total	***2,925***		***23,581,222***	

Figure C-2 Pilot Deviations and Take Off and Landing Operations By Time of Day

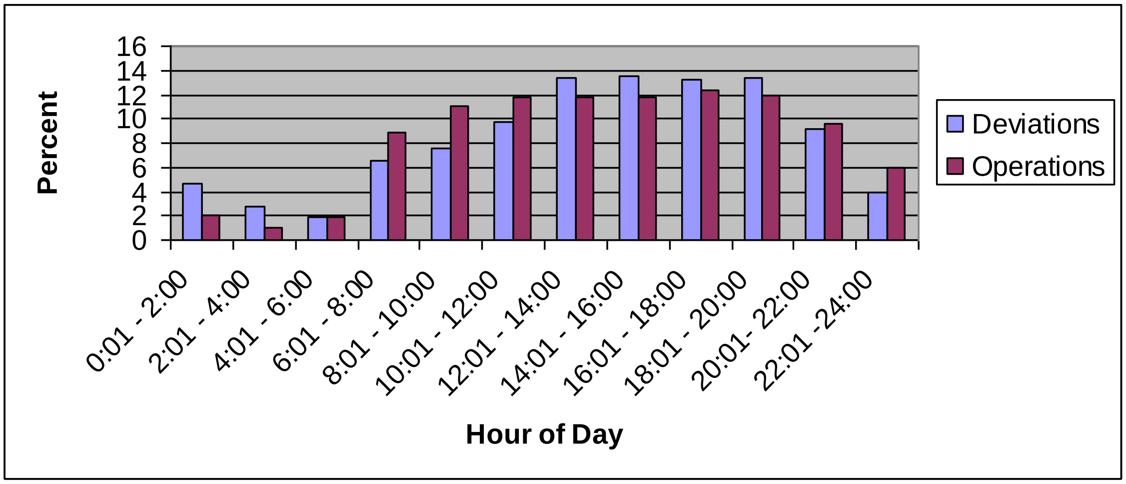


Table C-2 and Figure C-2 show that a higher percentage of deviations occur late at night (0:001 am to 4:00 am) than the percentage of takeoff and landing operations during those hours. The same can be said the afternoon and evening (12:01 pm to 10:00 pm). During the morning (4:01 am to 12:00 n) and late evening (10:01 pm to 12:00 m), the percentage of pilot deviations is lower then the percentage of operations during those times. That pilot deviations are high relative to aircraft activity between midnight and 4:00 am is not too surprising given that people least alert during that period of time when they are in their window of circadian low, but it is a bit of a surprise that deviations are relatively low between 10:00 pm and midnight when many people go to sleep. Most people are rested from a night's sleep and are most alert during the morning so deviation should be expected to be relatively low during that time. During the afternoon and evening, many people begin to become tired and less alert and deviations are expected to increase during that time.

Sometimes incidents have a more serious consequence than a deviation citation; sometimes the incident becomes an accident. The above findings for pilot deviation incidents also apply to accidents.