
THE EFFECT OF LINE MAINTENANCE ACTIVITY ON AIRLINE SAFETY QUALITY

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ABSTRACT

One of the arguments against deregulation of the airline industry has been the possibility that financially troubled carriers would be tempted to lower line maintenance spending, thus lowering maintenance quality and decreasing the overall safety of the carrier. Given the financial crisis triggered by the events of 9/11, it appears to be a good time to revisit this issue. This paper examines the quality of airline line maintenance activity and examines the impact of maintenance spending on maintenance quality and overall safety. Findings indicate that increased maintenance spending is associated with increased line maintenance activity and increased overall safety quality for the major U.S. carriers.

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INTRODUCTION

One of the key concerns of opponents of airline deregulation in the U.S. was that once carriers were free to compete based on the price of their goods rather than on the quality of their service, the quality of their safety would decline as the pressure to reduce costs increased (Lee, 1996; Rose, 1992). The question of safety quality in the airline industry has provoked intense debate over issues as basic as the definition of safety quality itself and as complex as the relationship between safety and financial performance. In the wake of 9/11, there is not only renewed interest in airline safety quality, but concern that financially troubled carriers burdened with additional security expenses might be forced to reduce safety spending and line maintenance activity. The purpose of this research is to explore the role of maintenance spending and line maintenance activity in the production of airline safety quality.

Background

Prior to 1978, the Civil Aeronautics Board (CAB) regulated both airline service quality and airline safety quality, establishing minimum standards for both. With the passage of the Airline Deregulation Act of 1978, U.S. airlines were free to determine market entry and exit, flight frequency, aircraft type, capacity, aircraft configuration, and the level of amenities provided (e.g., meals, entertainment, and seat pitch), based on market forces.

Establishing minimum standards and auditing for compliance is one of several ways to define and measure service quality. An airline survey such as those conducted by the publishers of Frequent Flyer and Condé Nast Traveler is another way. These surveys typically ask a cross-section of frequent flyers to rank airlines on key issues of customer satisfaction. Questions generally address the following ten factors of customer satisfaction: on-time performance, airport check-in, schedule/flight accommodations, seating comfort, gate location, aircraft interior, flight attendants, post-flight services, food services, and frequent flyer programs (Glab, 1998). While these surveys are an important source of information, it is difficult to compare the results of different surveys or to examine trends over time to gain a historical perspective of airline service quality. Aside from the quality awards created by the airlines themselves (e.g., the Grand Slam or Triple Crown), the most common method of defining and examining airline service quality is to use the results of the U.S. Department of Transportation's (DOT) monthly publication, *Air Travel Consumer Report*. This publication contains information on flight delays, mishandled baggage, over-sold flights, and consumer complaints filed with the DOT. In 1991, the Aviation Institute at the University of Nebraska at Omaha began using this data in its *Airline Quality Rating (AQR)* report (Bowen & Headley, 1991).

This report also includes key indicators of safety quality as well as financial stability. Unlike the survey method, the *AQR* and other studies using the data from the *Air Travel Consumer Report* have been criticized for focusing on basic service quality issues rather than the amenities (e.g., seating comfort and food service) that form a larger component of the typical survey (Perkins, 1998). The advantages of the *Air Travel Consumer Report* are its consistent historical reporting of data and public availability.

While airlines were now free to determine their own level of service quality, safety continues to be regulated by the Federal Aviation Administration (FAA). The FAA has authority to establish Federal Aviation Regulations (FARs) relating to: a) the design, manufacturing, and certification of aircraft, including their engines and other systems; b) the certification of airlines; and c) the certification of personnel who directly affect the safe operation of the aircraft, including pilots and mechanics. The National Aviation Safety Inspection Program was created to conduct focused inspections of airlines and maintenance facilities to insure compliance with all FARs. However, "there is also universal acknowledgement that full compliance with applicable safety regulation cannot be ascertained with existing or conventional methods of compliance surveillance" (Ozdener, 2000). Researchers have variously defined safety quality in terms of fatal accidents, accident rate and/or incident rate. Proxy measures of safety quality include operating profit margin, maintenance expenditure, and inspection results (Barnett & Higgins, 1989; Kanafani & Keeler, 1989; Rose, 1989; 1990; 1992).

According to the U.S. General Accounting Office (GAO), there are four factors that affect the safe operation of airlines: a) financial stability, b) maintenance quality, c) management attitude, and d) pilot competence (GAO, 1988; 1996). While pilot competence and managerial attitude have been cited in antidotal reports of accident investigation, there is little empirical data examining this link. One company, FlightSafe Consultants Ltd., does attempt to assess management effort as it relates to safety, but the assessment is subjective and not available to the public (Pasztor & Michaels, 2004). Research on the relationship between safety and overall financial performance has been mixed (Graham & Bowes, 1979; Kanafani & Keeler, 1989; Lee, 1996; Moses & Savage, 1990; Rose, 1990; 1992). The most commonly used measure of safety quality has been the level of maintenance expenditures, although this raw number can be misleading. Airline maintenance spending levels can be affected by a number of factors including the age of the aircraft in the fleet, the type and mix of aircraft, and the level of outsourcing (GAO, 1988; O'Toole, 1992). In short, to understand the issue of maintenance spending it is necessary to understand the nature of airline maintenance programs.

AIRCRAFT MAINTENANCE PROGRAMS

In an effort to maintain a comfortable degree of safety, a scheduled maintenance program is established for each transport category aircraft. For large aircraft, such a program is a process that can take up to five years to complete, and requires very close coordination between the aircraft manufacturer and operator (Hessburg, 2001).

The advent of modern scheduled maintenance programs began in the late 1960s with the Boeing 747. The sophistication and operating capabilities of the Boeing 747's aircraft systems and engines reached a point where maintenance programs currently in place were no longer considered effective. The Air Transport Association (ATA) created a Maintenance Steering Group (MSG) consisting of representatives of ATA-member airlines. This group created a document that became known as MSG-1. MSG-1 was process-and-procedures oriented. MSG-1 was soon followed by MSG-2, which was used with both the McDonnell Douglas DC-10 and the Lockheed L-1011 aircraft.

With the development of more sophisticated aircraft utilizing higher performance engines, glass cockpits, and advanced materials, the MSG-3 was introduced. The MSG-3 is a task-oriented rather than process-and-procedure-oriented document. Originally intended for the Boeing 757 and 767, MSG-3 has undergone three revisions, the latest including the Boeing 777 (Friend, 1997; Hessburg, 2001; Transportation Systems Consulting Corporation, 1999).

The actual purpose of MSG-3 is to establish the methodology that will be used to prepare the maintenance plan for a particular aircraft. An Industry Steering Committee (ISC) and various working groups are then established to create the plan. The purpose of the ISC is to oversee the activities of the working groups, each of which are composed of specialists in the various systems such as avionics, mechanical systems, structures, engines, and flight controls (Hessburg, 2001). The working groups in turn determine Maintenance Specific Items (MSIs) and specific tasks for their inspection and maintenance (Friend, 1997). Close cooperation between the regulatory agencies, the manufacturer, and the airlines is essential throughout the process.

The key to the process occurs early with a listing of the MSIs, that is, items that require specific inspections as determined by the appropriate specialists. After the list of MSIs has been determined, an analysis—known as decision tree logic—is performed on each item, with the key function being to differentiate between safety-related failure and economic failure. Servicing and maintenance requirements are determined at this time and include checks, inspections, lubrication, and when to discard. These requirements—known as tasks—are studied to the point where maintenance intervals can be defined in units of time called intervals. Intervals may

include hours, cycles, and calendars. The final product of the ISC and working groups are specific maintenance recommendations that include a list of items, tasks, and intervals. These recommendations are then presented to an FAA Maintenance Review Board that has approval authority, after which the necessary documents are developed (Hessburg, 2001).

The primary focus in aircraft maintenance, according to the FAA, is to provide continued airworthiness. Part 25 of the Code of Federal Regulations (CFR) prescribes airworthiness standards for the issuance of type certificates for Transport Category aircraft. The essence of the FAA regulation is that the instructions for continued airworthiness for each aircraft must contain inspection and maintenance information for not only the airframe, but also for every part of the aircraft, for example, appliances, engines, and propellers. Continued airworthiness data are typically in the form of manuals in paper, microfilm, microfiche, and/or CD-ROM format and organized in a specific manner. There will be general descriptions of the aircraft and its systems, basic operation of components and systems, servicing information regarding lubrication and capacities, troubleshooting information, methods of removing and replacing components, testing procedures, and specific details relating to inspections, maintenance, and servicing (FAA, 2003). Once the complete inspection package is developed, it is submitted to the FAA for approval. An FAA approved inspection program is then implemented as specified and takes the form of a number of different processes.

AIRCRAFT INSPECTIONS

For large aircraft, inspections fall into two broad categories: scheduled and special. Scheduled inspections include service checks, letter checks, phased checks, and calendar checks. The composition, scheduling, and even the titles of each inspection will vary with each operator. Regardless of the method used, the objectives behind such inspection programs are both safety and to increase aircraft availability.

Special inspection programs are the other major category of inspections performed on transport category aircraft, and, essentially, supplement existing scheduled programs. Special inspection programs—often the result of new technology or accidents/incidents—are approved by the FAA and coordinated with the aircraft and/or engine manufacturer. Aging aircraft inspections, corrosion control programs, Extended Twin-Engine Operations, low aircraft utilization, and Global Position Systems for navigation, are all cases where special inspection programs are utilized (Hessburg, 2001).

Scheduled Inspections

The most basic of the scheduled inspections is the service check. A service check includes checking and replenishing fluids, and inspecting for apparent deterioration, damage and security. These cursory inspections are

made at certain times during an aircraft's operating day. These inspections are made by line personnel, rather than by certificated technicians and are called, depending on their purpose, such names as preflight, throughflight, postflight, and overnight. Service checks are accomplished according to calendar time or flight hours depending on the requirements of the inspection program.

The most widely known type of inspections are the A-D letter checks, with an A Check being the most basic and frequent, and a D Check being the most comprehensive. All of these checks are accomplished at specified maintenance stations with the lower checks being accomplished along the route structure and the higher checks at a major maintenance base. The detailed and idiosyncratic nature of an inspection program is such that some items, for example on a B Check, may be accomplished every second or third check rather than each time a B Check is performed. Letter checks, as well as all other approved inspection programs, are customized to both the aircraft as well as the operator.

The A Check involves more detailed inspection than a service check, and focuses on servicing and periodic inspections of certain components on a daily basis. Some special tools and test equipment are required and the technicians performing them will have appropriate certifications. Fluid checks, system operations, and Built-In Test Equipment are all common with A Checks. A Checks typically occur twice per month, take 36 labor hours, and keep the aircraft out of service for approximately 12 hours (Hessburg, 2001). The B Check, which is no longer employed in many inspection programs, involves more in-depth servicing and testing. When performed, a B Check will take up to a 40 hour labor week to complete, are accomplished every four months or so, and keep the aircraft out of service for up to 12 consecutive scheduled flight hours (Hessburg, 2001). Items formerly performed in this type of check have been incorporated into either A Checks or C Checks.

The two remaining letter checks (C and D) are known as heavy checks and involve extensive inspection, testing, tools, and training. The C Check is the most common heavy check and is typically performed every 12 months or so. C Checks require approximately 450 labor hours and keep the aircraft out of service for as much as four days (Hessburg, 2001). Typical tasks performed during a C Check include detail visual inspections, specified systems functional testing, and major component lubrication. The most in-depth scheduled inspection is the D Check, which is predominately a major structural inspection designed to detect corrosion and fatigue failure through the use of sophisticated techniques such as Non-Destructive Testing. D Checks require as much as 1,500 labor hours and take a week or more to complete (Hessburg, 2001). Most operators have discontinued the D Check and have incorporated the various tasks into C Check intervals. An example

would be to inspect wing attached bolts every eighth C Check (or 16,000 flight hours). It is also important to note that each higher check includes all lower checks; for example, technicians performing a C Check would include items in both A Checks and B Checks as well as various service items.

A common way to distribute items contained in the heavy checks is to utilize a phased inspection program. A phase check is where parts of C Checks and D Checks are incorporated into lower A Checks and B Checks. For example, an inspection item scheduled to be performed in a C Check (which is typically performed every year or approximately 1,600 flight hours), will be incorporated into a B Check. While it will lengthen the B Check by perhaps a few hours, it will still only need to be performed once per year and the next B Check will include another part of the C Check. Over the period of a year, each C Check item is completed only once and the aircraft will not be out of service for the typical four consecutive days required for a complete C Check. When establishing a scheduled maintenance plan, the MSG will essentially describe tasks and intervals. The actual packaging of the inspection program into logical groupings is determined by the operator.

Service Difficulty Reports

Under 14 CFR section 121.703 and 135.415 of Title 14 (Code of Federal Regulations available at www.gpoaccess.gov/cfr/index.html) each holder of an airworthiness certificate must submit "reports on certain failures, malfunctions or defects of specific systems and on all other failures, malfunctions, or defects that, in the opinion of the certificate holder, have endangered or may endanger the safe operation of the aircraft." These difficulties may be discovered during the course of operations, or during inspections. Service Difficulty Reports (SDRs) are the publicly available record of line maintenance activity performed at repair stations, both those directly managed by the airline itself and outsource repair stations. This data are a key source of safety information for FAA inspectors as well as manufacturers interested in issues relating to the reliability and problems encountered with aircraft components.

Regulations require certificate holders to report specifically on matter relating to: a) a fire or fire warning system, b) an engine exhaust system, c) any aircraft component that causes the circulation of smoke or harmful vapors, d) any engine flameout or shutdown, e) a propeller feathering system, f) a fuel-dumping system, g) a landing gear system, h) a braking system, i) any component or system that results in a rejected takeoff or emergency action, j) any emergency evacuation system or component, and k) the autothrottle, autoflight or flight control system. 14 CFR section 121-704 deals with reporting related to structural defects or failures. These reports must specify the nature of the problem and the action taken. They must also identify any precautionary or emergency measures (called *procedures*) taken

to address the problems in question citing the categories above for reference (Rohrbach, 2004). From a glance at the above categories and those listed below for reportable procedures, the safety implications behind such actions as engine shutdown or a failure in the landing gear should be reasonably clear.

The reported data are entered and compiled into a database for weekly distribution to aircraft manufacturers, air carriers, repair stations, and the general aviation community. The raw data in the SDRs are available to the public through the FAA Web site (www.faa.gov) or other related Web sites such as www.landings.com. The FAA Aeronautical Center uses these reports to identify trends and significant safety issues. Based on this review of the database, the FAA may propose changes to existing procedures after due comment and may then issue an airworthiness directive or service bulletin.

In this study, we examined SDR history for the major U.S. carriers in order to understand the relationship between this measure of line maintenance activity (quality), maintenance spending, and safety outcomes, namely the number of procedures reflected on the SDRs. The historical nature of the data on the SDRs, their public availability, and close link to safety-related problems in maintenance appear to make them an excellent proxy for safety-related maintenance activity. Specifically, we wished to determine whether maintenance spending does improve the quality of line maintenance activity as reflected in the SDRs.

METHODS AND RESULTS

Data on safety outcomes were gathered from the FAA safety databases on accidents, incidents, and near mid-air collision. These data and the annual number of departures per carrier are contained in work previously conducted by Rhoades and Waguespack (1999; 2000; 2001). Data on line maintenance activity were collected from the Web site www.landings.com, which obtains the publicly available information directly from the FAA. Information collected included the total number of yearly SDRs filed and the total number of procedures by category. The categories are: a) unscheduled landing, b) aborted takeoff, c) aborted landing, d) engine shutdown, e) emergency descent, f) return to blocks, and g) deployment of emergency oxygen and/or fire activation systems. Information on maintenance spending was gathered from the *Air Carrier Financial Statistics Quarterly*, compiled by the Bureau of Transportation Statistics and published by the U.S. Department of Transportation. Information on the operational statistics (departures, miles, hours) was collected from the *Air Carrier Traffic Statistics Monthly* and the Bureau of Transportation Statistics. These data were used to normalize the safety and maintenance spending data for each carrier.

Table 1 shows the calculated figures for maintenance spending per mile flown for the carriers in this study. The last row on the table shows the mean maintenance spending per year. Spending rates below the industry mean are indicated. It should be noted that maintenance spending per year has increased for the industry overall between 1994 and 2000.

Table 1. Maintenance spending per mile flown, for U.S. airlines, 1994-2000

Airline	1994	1995	1996	1997	1998	1999	2000
Alaska	.0009*	.0008*	.0008*	.0010*	.0010*	.0012*	.0015*
AmericaWest	.0008*	.0009*	.0009*	.0012*	.0014*	.0016*	.0018*
American	.0014*	.0015	.0015	.0020	.0020	.0019	.0021
Continental	.0017	.0014*	.0014*	.0015*	.0016*	.0016*	.0016*
Delta	.0015	.0014*	.0013*	.0014*	.0015*	.0016*	.0018*
Northwest	.0017	.0018	.0021	.0021	.0025	.0024	.0029
Southwest	.0010*	.0010*	.0011*	.0010*	.0011*	.0013*	.0012*
TWA	.0019	.0019	.0021	.0020	.0020	.0020	.0020*
United	.0021	.0022	.0022	.0022	.0024	.0024	.0024
USAir	.0018	.0018	.0019	.0021	.0023	.0022	.0022
Mean	.0015	.0015	.0015	.0017	.0018	.0018	.0020

* Spending rate is below the industry annual mean

Note: The raw data are from *Air Carrier Financial Statistics Quarterly*, 1994-2000, Washington DC: U.S. Department of Transportation Center for Transportation Information.

Table 2 provides the ratio of procedures to total number of SDRs for these same carriers. If SDRs in general reflect the performance of routine maintenance, then—all other things being equal—a carrier performing more maintenance should demonstrate a higher level of maintenance quality, and thus a smaller number of procedures. A higher number of procedures, on the other hand, would not be a desirable outcome. We would expect the ratio of SDRs to procedures to be one indication of overall maintenance quality. In this case, Southwest stands out as being above the industry mean for 1994-1998, despite an excellent reputation for quality and an excellent record of safety.

Analysis of the relationship between maintenance spending, SDRs, and safety quality reveals a number of interesting findings. There does not appear to be a significant correlation between maintenance spending per departure, mile or hour and the total number of SDRs filed each year by the major carriers. There was a small correlation (.362) between maintenance spending per average haul and total SDRs. This is to be expected for two reasons. First, A Checks and B Checks are performed whenever a flight lands or terminates; airlines with short average hauls (total miles divided by

departures) would be expected to perform more of these checks. Second, much of the wear and tear on an aircraft is the result of the pressure changes experienced during ascending and descending. Aircraft flying short hauls can be expected to experience more of this type of stress.

Table 2. Ratio of reportable procedures to total service difficulty reports, for U.S. airlines, 1994-2000

Airline	1994	1995	1996	1997	1998	1999	2000
Alaska	9.24	11.35	21.63	12.17	59.78	101.44	53.10
America West	6.87	4.19	7.54	8.31	7.38	5.23	10.90
American	4.96	4.96	10.71	5.14	13.01	7.93	7.81
Continental	1.91	2.80	8.05	7.40	19.98	25.41	38.06
Delta	14.55	12.39	6.31	4.76	8.08	4.53	3.40
Northwest	3.41	3.08	5.82	3.90	3.64	5.44	3.85
Southwest	14.73	8.80	12.82	9.61	20.96	10.95	13.05
TWA	4.23	2.02	3.97	6.15	8.26	16.76	20.00
United	2.71	1.82	3.12	2.75	1.97	1.96	2.07
USAir	3.60	3.98	3.38	3.07	3.96	7.86	8.41
<i>Mean</i>	<i>6.62</i>	<i>5.54</i>	<i>8.34</i>	<i>6.33</i>	<i>14.70</i>	<i>18.75</i>	<i>16.06</i>

Note: The raw data on SDRs are collected from <http://www.landings.com>.

These same maintenance rates do show a significant, moderate correlation (.273-.522) with the number of reported yearly procedures indicating that maintenance spending increases with the level of procedures experienced in a given year. It is unknown whether increasing levels of procedures generate more maintenance costs to carriers or whether carriers increase maintenance spending as a result of increasing levels of procedures. Examining the relationship between the ratio of procedures to SDRs and maintenance spending, we found a significant negative relationship (-.328), that is, as the level of maintenance spending increases then the ratio of procedures to SDRs declines. Maintenance spending was also negatively associated with the total safety rate, that is, as maintenance spending increases the number of safety problems per year decreases.

DISCUSSION

Our analysis demonstrates that there is a relationship between maintenance spending rates and the level of both SDRs in line maintenance and the safety outcomes of the major carriers in the U.S. airline industry. As maintenance spending increased, carriers decrease the ratio of procedures to total SDRs. This is good news in several respects. Good routine maintenance appears to help lower the level of emergency and precautionary procedures. This in turn lowers the overall level of maintenance spending.

Increased maintenance spending also appears to decrease the number of safety problems experienced by airlines. This is the good news. As one articles recently stated, “[a]ircraft maintenance matters—a lot” (McCartney, 2004).

The bad news is that this relationship is not as simple as it would seem, nor does it appear to hold for all major carriers, leading to questions about the maintenance process itself. Southwest consistently posts a level of maintenance spending well below that of comparable major carriers and yet has an exceptional safety record. In part, this is due to the nature of their fleet which consists solely of B-737s. Maintaining a single aircraft fleet allows them to benefit from economies of scale in parts and equipment purchasing as well as lower training costs. United Air Lines, on the other hand, has posted a relatively high level of maintenance spending without any apparent improvement in safety outcomes. Of course, spending is not enough to guarantee safe outcomes nor can the total spending alone be used to judge maintenance quality since it is a function of fleet mix and age as well as the efficiency of the overall process and the stage at which potential safety problems are detected and corrected. Several recent articles have pointed to a key weakness in the maintenance field, namely FAA inspection. SDRs, while required of all repair stations, are covered under a fairly broad set of regulation. However, an effort by the FAA to tighten reporting to include a wider range of routine repairs and failures provoked an outcry from repair station operators (Rohrbach, 2004). Since reporting is and continues be subject to interpretation and individual carrier discretion, then active oversight of repair station operations is critical to ensure standards are met. Unfortunately, the FAA has been heavily criticized in recent years for its failure to provide adequate oversight, particularly of outsourced and foreign repair stations (McCartney, 2004; Pasztor, 2004; Alexander, Reed & Mellnik, 2003).

No study is without its limitations. In relying on SDRs, it is clearly possible that we have not fully captured the quality of line maintenance activity. The concept of quality in any area is a complex, multifaceted one. Maintenance quality is presumably a function of well-trained mechanics equipped with the proper tools and/or systems, utilizing parts that meet industry standards, and installing and maintaining them in ways proscribed by their manufacturer. However, these aspects of quality are not available to researchers. Data on the level of qualifications of the personnel hired by individual carriers are not available. Likewise, there is no source other than the airlines themselves (through voluntary reporting to researchers) of the level of corporate spending on training. Finally, as noted above, we must consider the accuracy of the SDRs themselves and the variation that exists between in-house and outsourced maintenance activities.

Future research should address the impact of fleet mix and age on maintenance spending as well as the actual reporting process itself. Based on our review, there appears to be a good deal of variation both within and between carriers in the number and type of events reported. The relationship between maintenance quality, as reflected by SDRs and procedures should be examined to understand their relationship to direct safety outcomes such as accidents and incidents. Other issues that should be addressed include the effect of aircraft utilization and maintenance training on overall maintenance spending and safety quality. This study should also be extended to examine these relationships for national and regional carriers.

Safety quality has been seen as an economic good that is both desired by consumers and costly to provide. Viewed in this context, "it no longer follows that the socially desirable level of safety is the highest that is both technologically and humanly possible," (Ozdener, 2000, p. 18) since such a level would be prohibitively expensive. Even when a consensus can be reached on an acceptable level of safety, it is difficult to observe safety directly. Regulators, firms, and researchers have tended to observe safety outcomes such as accidents, incidents, and near mid-air collisions and relate these to safety inputs such as financial condition, maintenance spending, and training spending. This study is only one step in understanding the complex process of airline line maintenance activity. This process has come under increasing scrutiny in the last several years due to a series of high profile accidents (e.g., Alaska Airlines Flt 261[2000], Flash Airlines Flt 504[2004]). While U.S. airlines continue to be some of the safest in the world, there is always room for improvement. Before this improvement can begin, it is necessary to develop a better understanding of the factors that affect maintenance quality and the processes that could be used to improve it. National and international organizations have been criticized for their failures to adequately oversee airline safety, particularly maintenance practices. Unfortunately, "outside groups and academics have made limited efforts to fill the gap" (Pasztor & Michaels, 2004, p. A14). This paper is one attempt to fill this very large gap. A gap we believe must be filled in order to provide consumers with the safety they expect and deserve.

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