A Reliability Analysis of Local Telecommunication Switches

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Abstract

This paper presents a reliability analysis of Local Exchange Carrier telecommunication switches in the United States, based upon empirical data. Telecommunication switch outage statistics are analyzed for a multiyear period, allowing examination into switch failure frequency, causes, and trends. Failure categories are created by reported outage cause codes, including human error, design error, hardware failure, and external factor causality categories. During this study period, the number of local exchange switches remained fairly constant in the public switched telephone network. The major result of this study is that, as a total population, local telecommunication switches exhibited reliability growth during this period, and failure event arrivals may be classified as a nonhomogeneous Poisson process (NHPP). Another result is that procedural, software design, and hardware design errors account for 40% of all local telecommunication switch failures.

Keywords: telecommunication, reliability, switches, public telephone network, ARMIS

INTRODUCTION

Historically, the Public Switched Telephone Network (PSTN) in the U.S. has been used predominantly for voice applications. With the exponential growth of the World-Wide-Web, the performance and reliability of the PSTN is receiving increased focus, as the PSTN is the primary means of non-business subscriber access to the Internet. Internet Service Providers (ISPs) are concerned about the continued ability of subscribers to reach their services through the PSTN. In fact, subscribers, businesses, Carriers, ISPs, and regulators all have a stake in PSTN reliability. Continuos improvement requires documenting today's performance, and measuring against that baseline. It is important to know reliability trends, not merely to predict, but to influence the future in a proactive way. The key to managing highly reliable systems is the recognition of an important precept – a reliability trend does not have to be accepted and actions may in fact be taken to alter the trend [1]. In order to change a trend, we look for approaches that will offer insights into why failures are occurring. Telecommunication switch reliability is determined by the complex interaction between software, hardware, operators, traffic load, and a variety of environmental factors. By knowing failure causes, designers (switch vendors) and operators of telecommunication switches (Carriers) may take corrective action to alter future trends. There has been a paucity of published empirical research concerning the reliability of telecommunication switches in the US. This paper addresses the following questions regarding telecommunication local switch reliability:

Research Question 1: Is the reliability of local telecommunication switches in the U.S. improving, constant, or deteriorating?

Research Question 2: What are the primary causes of local switch failures, and are there trends in these causes?

Reliabilit*y* is the probability a system will perform its intended function, in the intended environment and at a particular level of performance. Thresholds are very commonly used to declare a system as in either an "operational" or "degraded" mode [4]. If the system is in a degraded mode, there is a failure event. Therefore, for this paper we will principally analyze failure events to assess reliability.

CONTEXT

Although the PSTN is a complex system, its functions are executed by the close cooperation between switching, signaling and transmission entities. These entities cooperate in order to provide circuit switching, or the establishment, maintenance and termination of end-to-end connections between subscribers through a network. The switching entities are responsible for concatenating individual transmission links into an

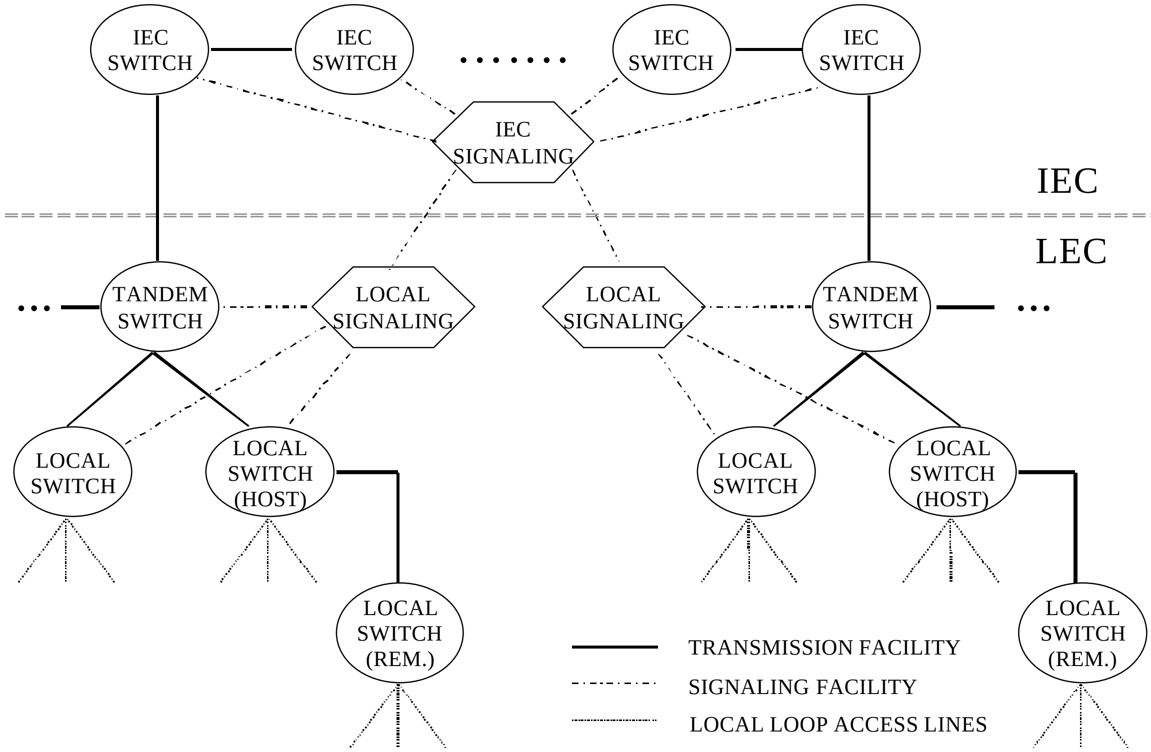

Figure 1. PSTN Infrastructure

end-to-end connection, while the signaling entities coordinate the establishment, maintenance and termination of the end-to-end circuit. Lastly, transmission entities provide links between switches. In the United States, an end-to-end circuit might involve a number of different telecommunication Carriers. Although the Telecommunications Act of 1996 may radically change the telecommunication landscape, the typical long distance call currently involves an originating Local Exchange Carrier (LEC), the Interexchange Carrier (IEC), and the terminating LEC, as shown in Figure 1. Local switches are defined as those having local loop access lines connected, including standalone, host, or remote local switches. Tandem switches that also have access lines, or access tandems, are also included in this study, but represent a small number of the total population.

In this work, the PSTN is viewed as a single system, made up of switching, signaling and transmission segments. The switching segment is made up of the tandem and local switch subsystems, as shown in Figure 2. The purpose of this paper is to investigate the reliability of the *local exchange switching subsystem* as a whole, by investigating the pooled failures of all individual local switches in the PSTN. There are a large number of different manufacturers and models of local switches in this infrastructure. Even the same model switch varies substantially from serial to serial because of differences in customers served and features offered. The right censored approach on *n* identical items on test is not a good model, as it can be argued that no two switches are exactly alike, in size, configuration, or environmental setting. By pooling failures from different switches, we may assess the reliability of local switching as a whole, rather than the reliability of a single switch.

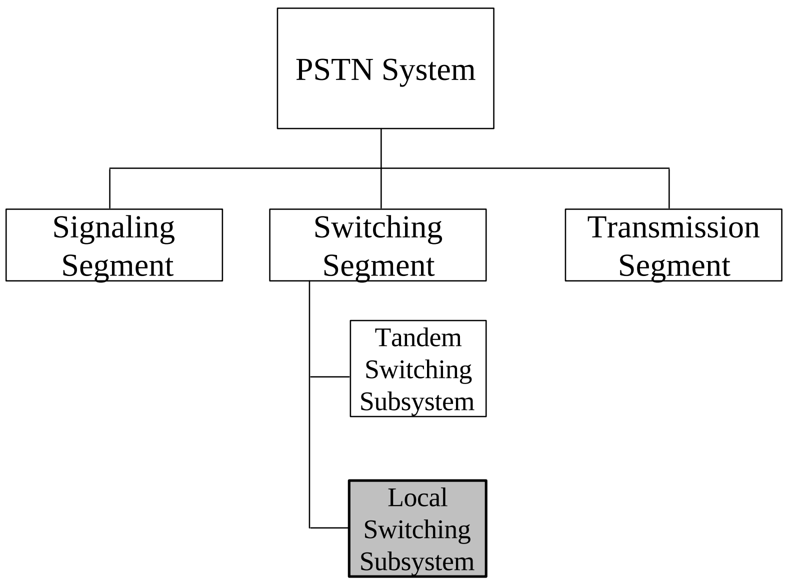

Figure 2. Systems Perspective of the PSTN

EMPIRICAL DATA

Individual switch outage incidents of at least two minutes in duration are reported to the Federal Communications Commission (FCC) by all price cap regulated LECs, accounting for over 90% of the telephone access lines in the U.S. This data is part of the quality-of-service statistics required by the Automated Reporting and Management Information System (ARMIS) reports made to the FCC by LECs. For each reported switch incident the date, time, duration, and outage cause are included, along with the number of access lines connected to the switch experiencing the outage. Very importantly, the reporting Carrier classifies each incident using one of fifteen different cause codes. This research presents a comprehensive reliability analysis of LEC local telecommunication switches in the United States using this public data over an extended period, January 1991 through December 1995. From January 1991 through September 1992, quarterly counts of outage incidents are given, while for outage events from October 1992 on, the date and time of the event are also included. This multiyear data set allows a number of different investigations into local switch reliability using the number of incidents during this period. During this study period, the number of local exchange switches remained fairly constant in the PSTN [7].

The two-minute reporting threshold is recognized as a reliability threshold in this study. An outage is different from a failure event, as the outage also has a duration (how long the switch failed) and a size (how many subscriber lines connect to the switch). Availability and survivability are also important aspects of switch quality-of-service, but not in the scope of this study. The former includes treatment of both frequency and duration, while the latter also deals with importance, such as number of subscribers affected and time of day. The results presented below make an important distinction between an outage and a failure event.

SUMMARY ANALYSIS

As mentioned, the reporting Carrier attributes an individual switch outage incident to one of fifteen different cause codes, as required by the ARMIS reporting instructions. It is important to note that only total switch outages are reported. A partially failed switch is not a reportable outage, irrespective of the size of the partial switch outage. An abbreviated definition for each cause code and the number of outages reported for each category is shown in Table 1. It is interesting to note that for this five year period over half of the outages were planned outages. From here on, a distinction is made between a *failure* and an *outage*. Cause code one is recognized as an outage, while cause codes two through fifteen are treated as failures. Since about half the events are failures, the percentage distributions of failures are about two times the percentages shown in Table 1.

Another way to summarize the failure data is to combine some of the codes into categories that might offer more insight into the reliability performance of local switches. The following categories are created by combining cause codes:

- Human error: Procedural errors made in installation, maintenance or other activities by Telco employees, contractors, switch vendors, or other vendors.
- Design error: Software or hardware design errors made by the switch vendor prior to installation.
- Hardware error: A random hardware failure, which causes the switch to fail.
- External circumstances: An event not directly associated with the switch which causes it to fail or be isolated from the PSTN.
- Other/unknown: A failure for which the cause was not ascertained by the Carrier.

These categories, their composition, and the distribution of failures to each category are shown in Table 2. Several observations can be made from this sub-grouping:

- Human error, design error and random hardware failures account for about *60%* of all failures, in roughly equal proportions (A similar result for a much shorter time period and a five minute threshold is reported in [6]).
- Human and design error account for about *40%* of all failures.
- The largest category is other/unknown.

If the other/unknown true causes are uniformly distributed among the other categories, then the previously mentioned proportions are valid. The analysis above is invariant and care must be exercised not to base conclusions solely upon these statistics.

Another perspective for this failure data is a periodic count viewpoint, which will offer the first hints of whether the outages and failures, are constant, increasing, or decreasing. A time series plot of quarterly counts is shown on Figure 3, from which we may visually conclude:

- Scheduled outages per quarter are roughly equal to failures, with notable exceptions for three consecutive quarters.
- A decrease in quarterly outages and failures starts in first quarter 1995.

The latter point is strongly suggests reliability growth, and a time-series-of-event investigation might be fruitful.

Table 1. Local switch outage and failure cause distribution

Code	Description	Number	Percent
1	Scheduled	10,234	54.4%
2	Procedural error (Telco install./maint.)	650	3.5%
3	Procedural error (Telco non-install./non-maint.)	388	2.1%
4	Procedural error (System vendor procedural error)	304	1.6%
5	Procedural error (Other vendor procedural error)	244	1.3%
6	Software design	1,625	8.6%
7	Hardware design	227	1.2%
8	Hardware failure	1,900	10.1%
9	Acts of god	403	2.1%
10	Traffic Overload	42	0.2%
11	Environmental	77	0.4%
12	External power failure	97	0.5%
13	Massive line outage, cable cut, other	103	0.5%
14	Remote - loss of facilities between host/remote	233	1.2%
15	Other/unknown	2,281	12.1%
	Total	18,808	100.0%

Table 2. Local switch failure cause category distribution

Codes	Failure Category	Number	Percent
2,3,4,5	Human Procedural Error	1,586	18.5%
6,7	Design Error	1,852	21.6%
8	Hardware	1,900	22.2%
9,10,11,12,13,14	External Circumstances	955	11.1%
15	Other/unknown	2,281	26.6%
2 through 15	Total	8,574	100.0%

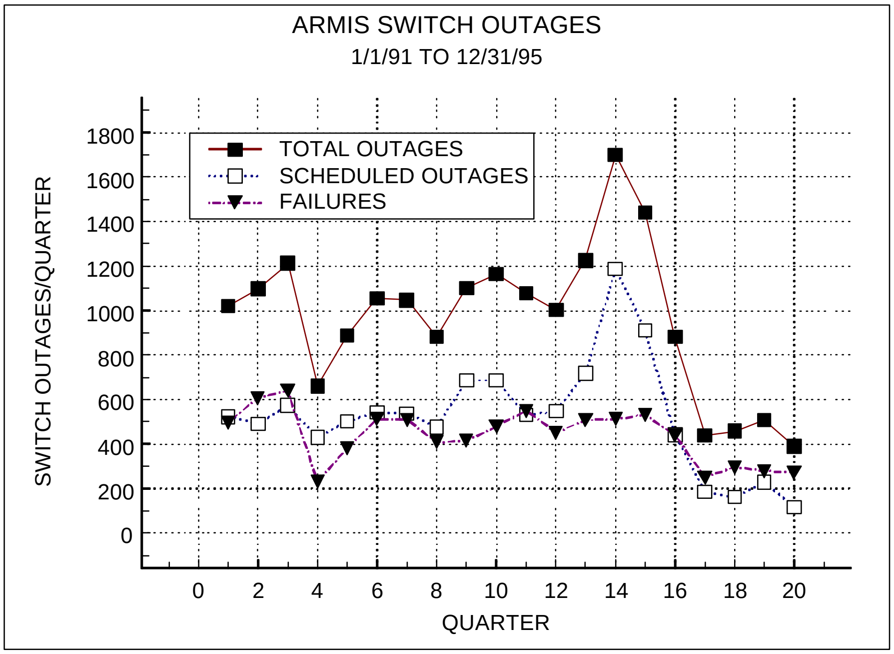

Figure 3. Local switch outage time series

TIME SERIES OF EVENT ANALYSIS

Here the outage data is investigated for trends and process classification. The perspective here is that the PSTN is viewed as a single repairable system, and that we are investigating the local switch subsystem. The first method in assessing a trend is visual, using the cumulative failures versus time plot. A linear plot (constant arrival) is a necessary condition for a homogeneous-Poisson-process (HPP), but the time-to-failures must also be i.i.d., where the distribution of times-to-failure is exponential. If the events are i.i.d. and the distribution is other than exponential, then we may classify the process as renewal [4]. However, if the cumulative plot bends downward or upward, the failures are not from a common distribution, and we have either reliability growth or reliability deterioration, respectively [2]. In this instance, the most common classification is nonhomogeneous Poisson process (NHPP).

The Cox-Lewis trend test (Laplace test) is used to formally test for trend, where the homogeneous Poisson process (HPP) is the null hypotheses. In this test, the test statistic rapidly converges to a normal score with very few data points [3]. In addition, the Lewis-

Robinson trend test is used where the renewal process is the null hypotheses. In this test, the Laplace test statistic is divided by the coefficient-of-variation (CV) of the times-to-failure [2]. Event independence tests are made using first autocorrelation coefficients of the times-between-failure [3].

The trend and independence test results are shown in Table 3, where the critical values (α) for rejecting the null hypotheses (HPP, renewal, and independence between events) are shown. Note that the number of outages/failures for each code is different than that depicted in Table 1 because consistent reporting of the actual date and time of the outage did not occur until October 1, 1992. Prior to this date only quarterly count data is available – this data is not included in this time-series-event analysis as the date and time of the event is required. For this shorter 3.25 year period, the most remarkable difference is in the Other/unknown (*2281* to *352*) and Scheduled (*10,234* to *6461*) categories. So the Carriers' fault isolation reporting apparently improved, and the need for scheduled outages apparently decreased after October 1992.

Also, note the significant overdispersal, or bunching of events, as indicated by the coefficient-of-variation values greater than unity. This suggests that the Lewis-Robinson test is a better indicator of trend, as it tests the more general renewal case where bunching is often initially observed. The category groupings show very strong negative trends and dependence, allowing a classification of NHPP [2]. As the trend scores are negative, decreasing number of events, or reliability growth is indicated in these causal categories. A visual perspective of these strong statistical inferences of a negative trend for scheduled outages (Code 1) and all failures (Codes 2 through 15) are shown in Figure 4, where the cumulative plots versus time are shown. Here we see a very pronounced bend in each plot corresponding roughly to January 1995. The cumulative plots for the design error, random hardware failure, and human error are shown in Figure 5. Note that design error, random hardware failures and human error account for roughly the same number of local switch failures. Design error and hardware failures both indicate strong reliability growth. The human error trend is not as statistically strong, however a visual break is apparent at about January 1995. In fact, human errors show three distinct regions of reliability performance - moderate, poor and good reliability regions.

Table 3. Local switch failure trend and independence tests

Population (No.)	$U(a)$	CV	$U_{LR}(a)$	$r_1\sqrt{n-1}(a)$
Sched. Outage (6461)	-25.47 (0.000)	2.479	-10.28 (0.000)	8.341 (0.000)
Human Error (1,291)	-2.450 (0.014)	1.490	-1.645 (0.100)	3.547 (0.000)
Design Error (1,450)	-10.53 (0.000)	1.366	-7.71 (0.000)	5.437 (0.000)
Hardware Error (1,425)	-4.921 (0.000)	1.242	-3.961 (0.000)	2.180 (0.029)
External Circum.(604)	-5.872 (0.000)	1.502	-3.910 (0.000)	8.060 (0.000)
Other/Unknown (352)	-2.614 (0.009)	1.371	-1.906 (0.057)	2.341 (0.019)
Total Failures (5123)	-12.15 (0.000)	1.404	-8.66 (0.000)	10.37 (0.000)
Code 2 (524)	-0.247 (0.805)	1.459	-0.169 (0.866)	2.763 (0.006)
Code 3 (321)	-2.491 (0.013)	1.263	-1.972 (0.049)	1.263 (0.207)
Code 4 (238)	-3.011 (0.003)	1.379	-2.184 (0.029)	1.379 (0.168)
Code 5 (208)	0.602 (0.547)	1.743	0.346 (0.730)	1.743 (0.081)
Code 6 (1,238)	-8.953 (0.000)	1.315	-6.807 (0.000)	1.315 (0.188)
Code 7 (212)	-5.902 (0.000)	1.659	-3.557 (0.000)	1.659 (0.097)
Code 8 (1,425)	-4.921 (0.000)	1.242	-3.961 (0.000)	1.242 (0.214)
Code 9 (204)	-1.008 (0.313)	2.142	-0.471 (0.638)	2.142 (0.032)
Code 10 (31)	-2.200 (0.028)	1.310	-1.680 (0.093)	1.310 (0.190)
Code 11 (52)	0.142 (0.887)	1.528	0.093 (0.926)	1.528 (0.127)
Code 12 (77)	-2.141 (0.032)	1.353	-1.582 (0.114)	1.353 (0.176)
Code 13 (93)	0.472 (0.637)	1.602	0.295 (0.768)	1.602 (0.109)
Code 14 (148)	-8.728 (0.000)	2.666	-3.274 (0.001)	2.666 (0.008)

Next, the individual cause codes are visually examined for trend. A comparative plot of procedural errors is shown in Figure 6 where a breakpoint in Telco installation and maintenance is apparent, after a period of escalating failures. A comparative plot of hardware design and act-of-god failures is depicted in Figure 7. Note the steady reliability growth of overall switch hardware design. Next, a comparative plot of random hardware failures and software design failures is shown in Figure 8, depicting strong reliability growth in these categories. Figure 9 is a comparative plot of external power, environmental and traffic overload induced failures. Note the reliability growth in power outages, indicating perhaps Carrier upgrades to uninterruptable power systems (which in turn made switches less susceptible to external power outages). Next, a comparative plot of the two different cases of switch isolations from the PSTN due to transmission system failures is seen on Figure 10. Note the strong reliability growth in these categories. Lastly, the other/unknown failures are shown in Figure 11. Although the overall trend is down, for last two years of the study period it is constant.

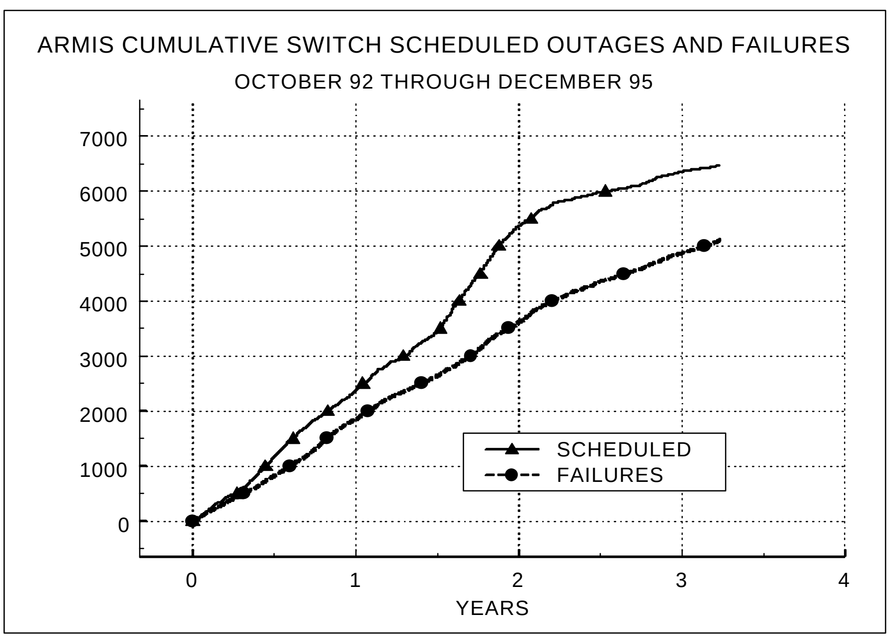

Figure 4. Scheduled outage and failure cumulative plot comparison

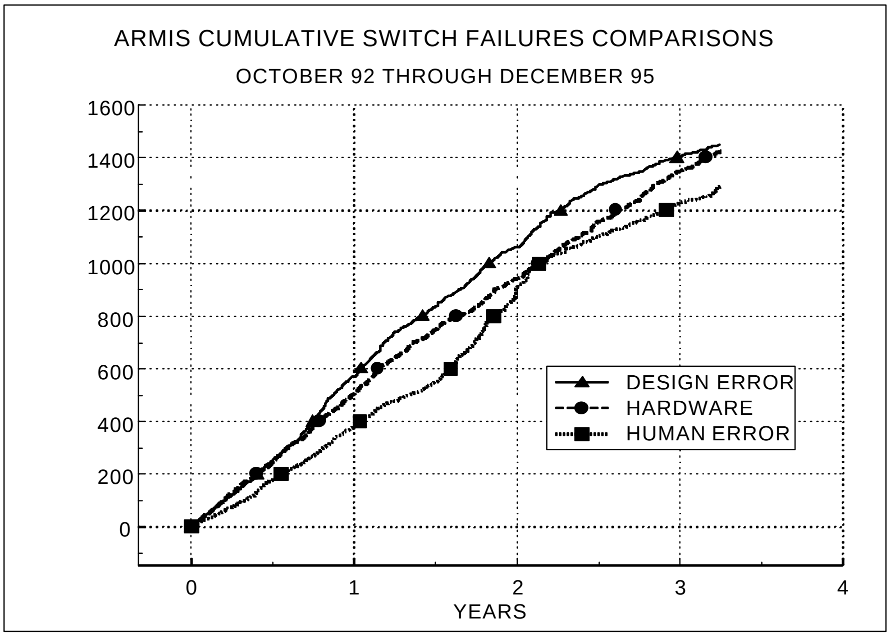

Figure 5. Design error, hardware failure, and human error comparisons

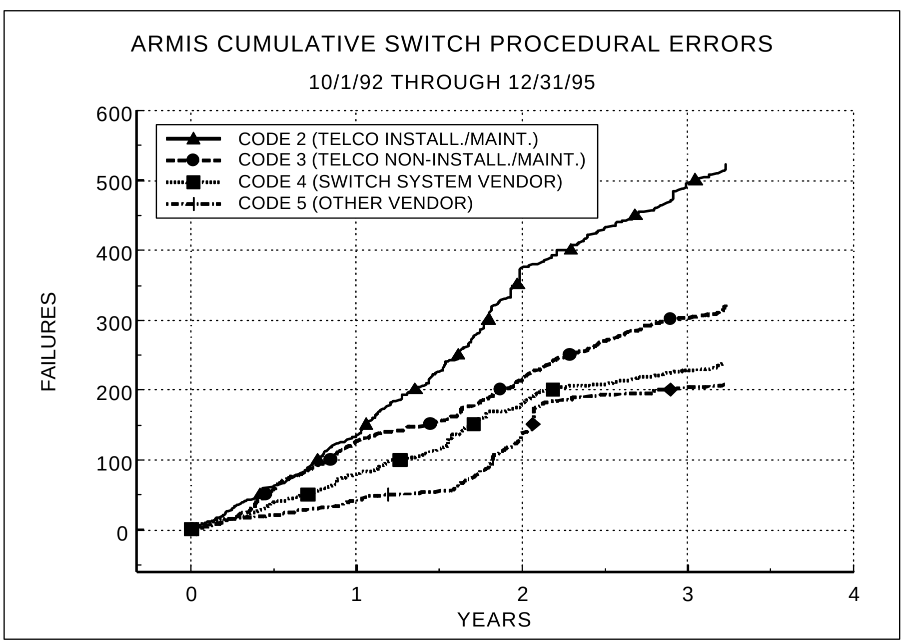

Figure 6. Procedural error cumulative plot comparisons

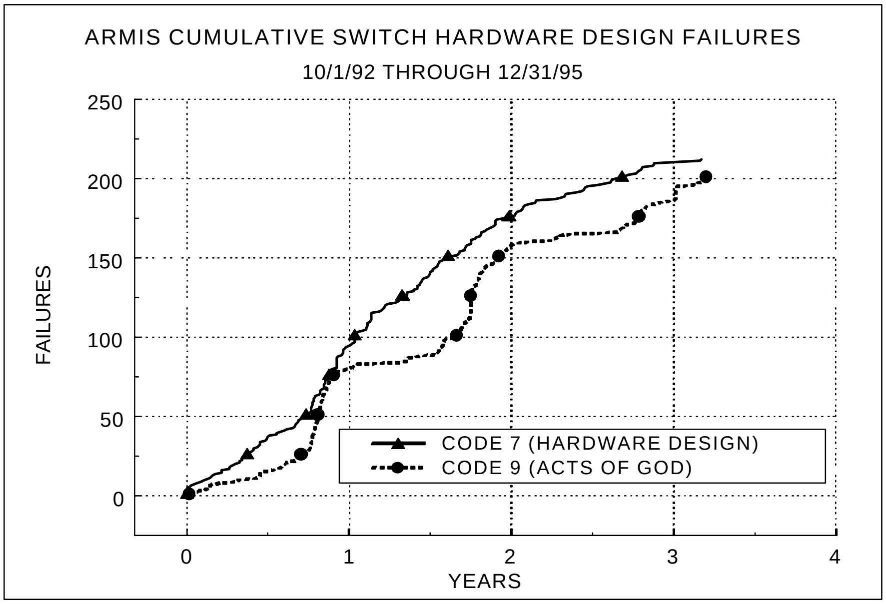

Figure 7. Hardware design and act of god cumulative plot comparisons

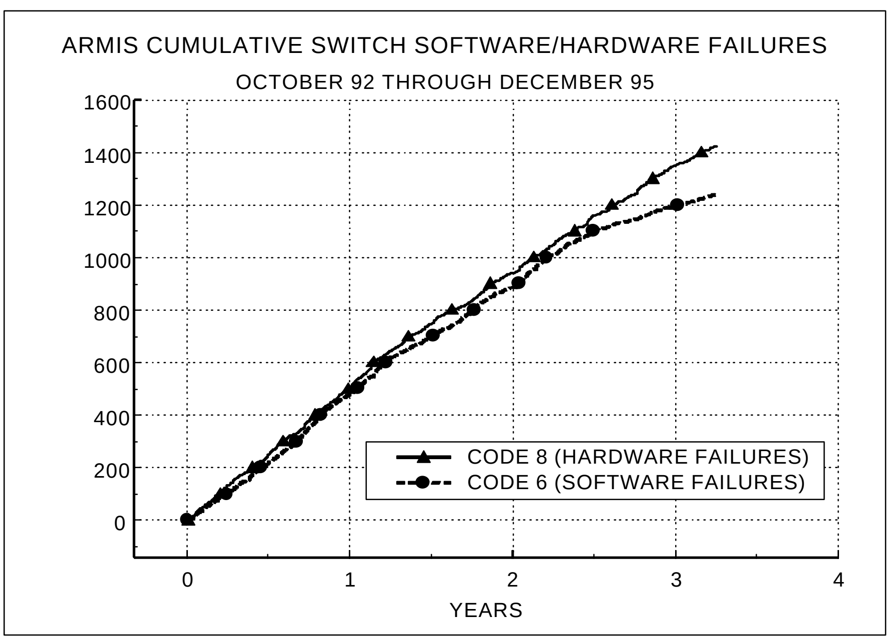

Figure 8. Hardware and software failure cumulative plot comparisons

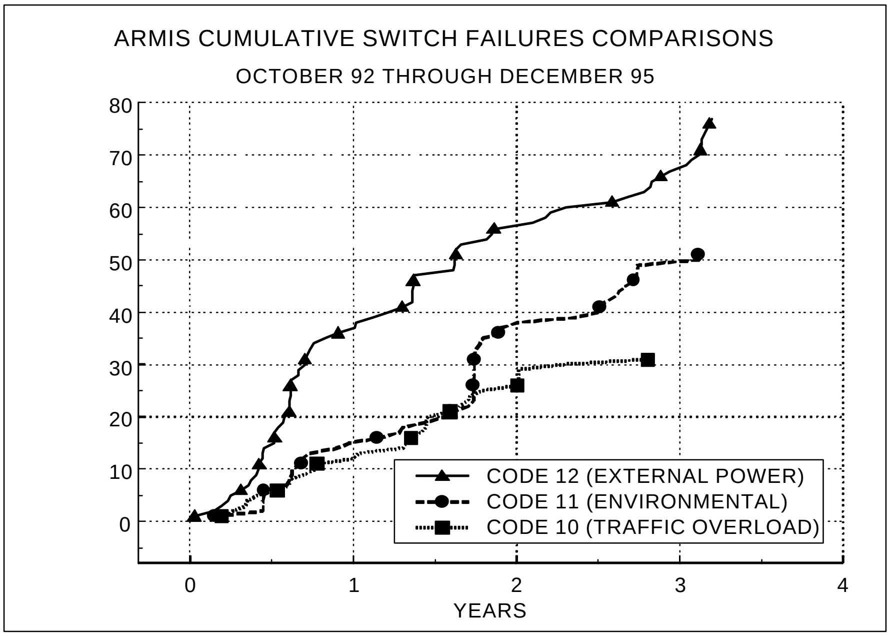

Figure 9. Power, environmental, and traffic failure of god cumulative plot comparisons

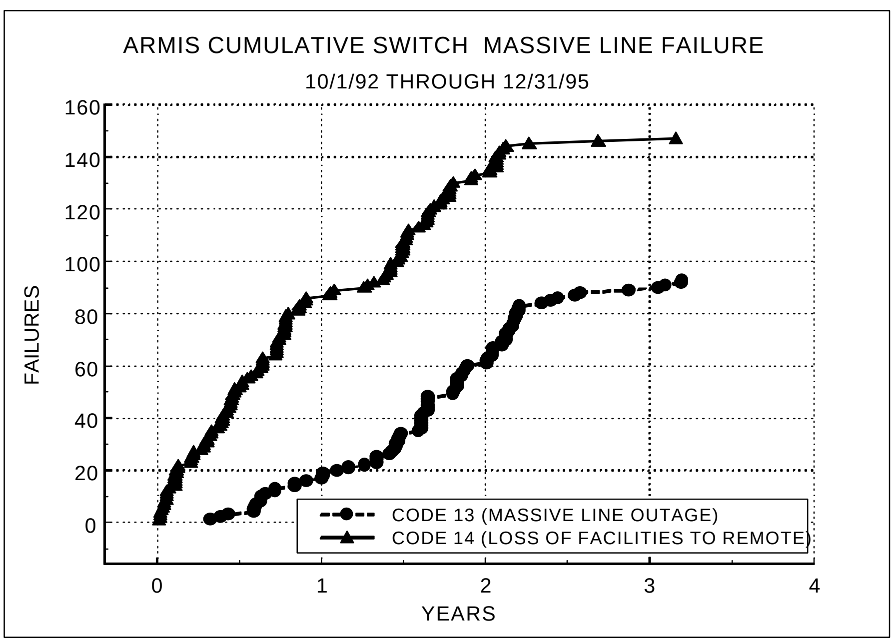

Figure 10. Transmission facility failure cumulative plot comparisons

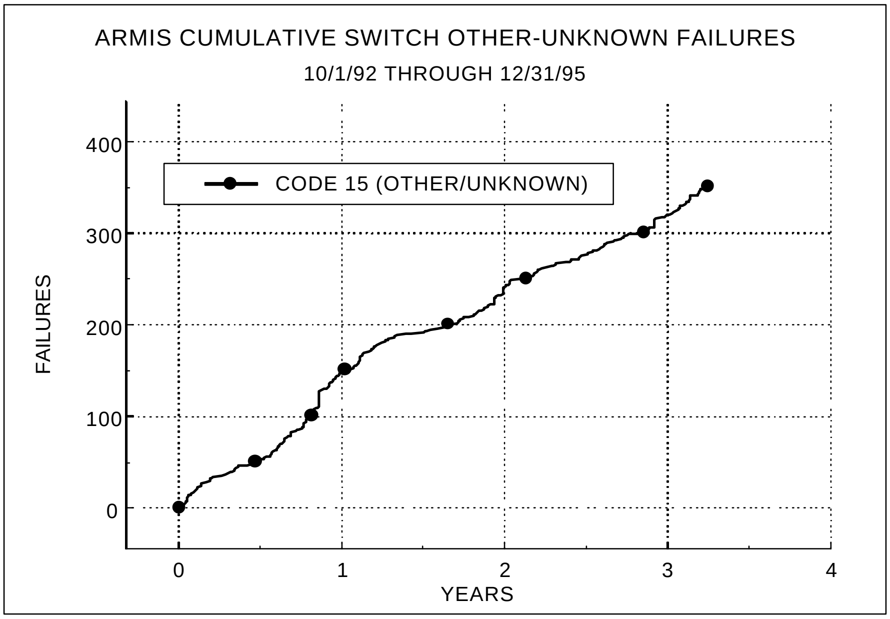

Figure 11. Other/unknown cumulative plot

DISCUSSION OF RESULTS

A time-series-event analysis provides additional insights into local switch reliability, which are not apparent from an invariant summary statistic perspective. However, both perspectives of reliability are a function of the reliability threshold chosen here, switch outages reported of at least two minutes in duration. A different threshold could mean different results and conclusions. In fact, when the reporting threshold is 30 minutes and a minimum of 30,000 users affected, the failure rate is relatively constant for local switches, and no reliability growth is observed [7].

A pronounced decrease in scheduled outages occurs about January 1, 1995. This date coincides with the date the Network Reliability Council, a Federal Communications Commission federal advisory group, recommended that the industry find a way to curtail scheduled outages [6]. The primary purpose of scheduled outages had been periodic software/feature and memory upgrades taking place predominately during early morning hours. In the case of a large switch vendor (Nortel), the reason for the decrease in outages relates to the ability of vendor engineers to perform much of the upgrade work remotely, rather than depending solely on on-site Telco technicians. In addition, a way was devised to not take both switch processors down at the same time when new software release/feature changes are made, decreasing the chance of a switch failure [5]. The same January 1995 breakpoint is observed in a variety of the failure categories, possibly indicating that scheduled outages were also causing other reported operational failures.

In addition to these strong trends, strong dependence is also observed, allowing an NHPP classification. This also suggests over-dispersed failure events (corroborated by the large coefficients of variation), possibly due to closely scheduled nationwide or regional activities associated with large vendor software releases and feature upgrades.

CONCLUSIONS

The research questions posed earlier have been addressed. The reliability of local communications switches improved over the period October 1992 through December 1995. This work sheds light on this important facet of PSTN reliability based upon strong statistical inferences, rather than speculation, anecdotal evidence, or engineering - operational judgements. Lastly, the principal known causes of local switch failures are found to be human (procedural) error, design error, and random hardware failure. In fact, over 40% of all local switch failures are due to procedural or design problems.

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