A Reliability and Survivability Analysis of US Local Telecommunication Switches

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***Abstract*— This paper presents a comprehensive analysis of the reliability and survivability of US local telecommunication switches over a 14-year study period (from 1996 to 2009). Using local switch outage empirical data, the causes, failure trends and impacts have been identified, analyzed and assessed. A total of 12,860 switch outages were investigated for which very significant reliability growth was identified over the study period. Outages were also studied temporally, from time of day, day of week, and month of year perspectives. Additionally, 2,623 of the outages were found to come from only 156 unique switches, each of which experienced eight or more outages over the study period. The data were separated into two categories, for comparison: more frequently failing switches and less frequently failing switches. Major findings are that scheduled maintenance activities and hardware failures are the major causes of outages in local telecommunication switches; there are significant causality differences between more frequently and less frequently failing switches; and there are considerable differences in switch characteristics between the more and less frequently failing switches. Additionally, the manufacturers of the more frequently out switches are identified.**

Keywords-network reliability; reliability trends; public switched telephone network; local telecommunication switches

I. INTRODUCTION

Early in 2013, research on local communication switches suffering frequent outages was reported in [1]. This work is expanded here, not just to switches with frequent outages, but to all local switches experiencing outages over a 14 year period. Additionally, in this paper, information on frequently out switches is expanded to include manufacturer. In this section, the research purpose, importance, and scope of this work are discussed.

A. Research Purpose

As an extension and expansion of previous research, this study analyzes the reliability and survivability of US local switches using data on Public Switched Telephone Network (PSTN) local switch outages. In addition to that, this study determines if a minority of switches account for significant reliability or survivability deficits in this important component of the PSTN. This study also examines local telecommunication switch outage trends and causes. Finally, the national policy regarding local switch outage collection regulations is briefly assessed.

In this study, the PSTN is considered as a single repairable system. A repairable system is defined as a system that passes from an operating mode to a failed mode, and then returns to operating mode after a certain period of time [2]. In fact, the system is returned to the operating mode by means other than replacing the entire system. As local switches serve as access nodes for users, it is important to understand switch outages in their natural operating setting.

B. Research Importance and Scope

Analyzing the reliability and survivability of local switches is of great importance because it can help in monitoring and improving the efficiency of the entire PSTN switching system since local switches form a large percentage of all the PSTN switches. Additionally, mobile and fixed wireless systems will always benefit from the reliability and survivability of the PSTN switching system because they greatly depend on it. This is especially true when wireless subscribers want to communicate with landline subscribers or call wireless subscribers in a different geographical area. The reliability assessment of local switches, which also includes determining the nature and trend of failure events, can help designers (switch manufacturers) and operators (service providers) in taking corrective or preventive actions where needed. Also, investigating the causes of outages in PSTN local switches can help in improving wireless switches, as they are very similar to wireline switches (i.e., same vendors and similar models). Definitely, the reliability of the PSTN is crucial, as it is the heart of landline and mobile voice communications.

The PSTN is a complex system composed of three main systems, namely the switching system, the signaling system, and the transmission system. The switching system controls and routes voice or data signals throughout the network. The signaling system enables switches to cooperate in call initiation, maintenance, and termination. Finally, the transmission system ensures physical connections between switches. These three systems enable end-to-end connections among PSTN subscribers. The signaling and transmission systems are not included in this study.

The switching system can also be subdivided into subsystems that include, the local exchange switching subsystem (local switches), the tandem switching subsystem (tandem switches), and the international gateway exchange subsystem (access switches) (Fig. 1). Only the local exchange switching subsystem is investigated in this study. Local switches include standalone, host, and remote local

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switches. As an exception, some tandem switches also have access lines, and although they are included in this study, they represent a very small percentage of all reported switches or more outages. This study investigates reported local telecommunication switch outages in the U.S. of at least 2 minutes in duration for a 14-year period (1996-2009) and considers only totally failed switches rather than partially failed switches. Data below 2 minutes and partially failed switches are of interest, but not reported by the carriers.

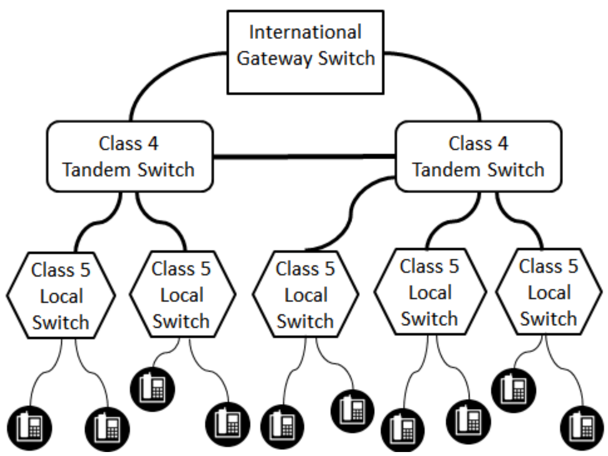

Figure 1. The PSTN switching system.

Again, the local exchange switching subsystem is analyzed as a whole, where all outages of individual local switches are pooled to analyze the overall reliability and survivability of the PSTN local exchange switching subsystem. Availability, safety, security, maintainability are other system dependability attributes not assessed in this study. Also, the calculated impact of outages includes only access lines but not blocked calls, as blocked call data were not reported.

In industry, local switches are called by different names, including “class 5 local exchange switch”, “local switch”, “central office switch.

II. LITERATURE REVIEW

In this section, a review of previous relevant research is presented in order to assess areas of focus of past researches, and establish a relationship between those studies and this research. The information presented was gathered from different sources, both electronic and non-electronic; including, but not limited to, research papers, books, conference papers and journals.

A. *Past Studies on Local Telecom Switch Outages*

There have been very few published research papers focusing on the reliability or survivability of US local telecommunication switches. In a previous research study, Snow analyzed local switch outages from 1991 to 1995, finding significant reliability growth [3]. Also, a few results regarding frequently failing switches were reported, but not studied in [4]. Kuhn studied local telecommunication switch outage records reported by telephone companies to the Federal Communication Systems (FCC), consisting of outages affecting at least 30,000 customers for at least 30 minutes. From those records, covering the period April 1992 through March 1994, Kuhn reported that the principal causes of PSTN large-scale outages were human error, acts of nature and traffic overloads [5].

Later, Snow investigated the effectiveness of the FCC outage reporting threshold, consisting of all reported outages affecting at least 30,000 users for at least 30 minutes. He used over 18,000 local telecommunication switch outages above and below the FCC reporting threshold and reported that the FCC outage reporting threshold was not optimal [6]. Again, Snow and Agarwal investigated over 19,000 local switch outages that occurred over the period 1993 through 2002 in order to explore an optimal outage reporting threshold that could reduce the number of outage reports and at the same time allow enough insight into network survivability. They found that “PRODUCT” thresholds such as lost line-hour (lines out times outage duration) are more optimal than AND (lines and duration) thresholds for assessing the survivability of telecommunication networks [7].

B. *PSTN Overview*

The PSTN, which is a collection of interconnected voice-oriented public telephone networks, was originally designed to support circuit-switched landline (or fixed line) voice communication. However, it is also used as the backbone network of mobile (or wireless) voice communication. Some of its elements are also used for Internet based network technologies such as Voice over Internet Protocol (VoIP). PSTN subscribers are connected to the PSTN network through local loops, which physically connect users’ homes to central or local offices switches (also known as class 5 switches or end offices switches) [8]. In fact, local class 5 switches are the access and delivery points of voice communication to and from landline subscribers, and they receive numerous software upgrades during their lifetime in order to meet user and network ever-changing requirements.

Currently, most of the PSTN core system uses digital switching and transmission whereas many local loops still use analog mechanisms. It is clear that today’s PSTN is transitioning to a packet switching, IP-based network, but this transition will not happen overnight. It will take many years to transition the entire PSTN into an all-IP-based network, especially the local loops [9]. In fact, although most of the interoffice transport network has been replaced by IP technology, the majority of the PSTN customers are still connected to the PSTN through local circuit-switched networks [9]. A recent report found that, “[in] December 2010, there were 117 million end-user switched access lines in service and 32 million interconnected VoIP subscriptions in the United States…” [10].

In fact, many network operators (services providers) want to provide a smooth migration from the legacy PSTN to a Next Generation Network (NGN), so they decided to consider changes to local loop networks only when expanding them or when replacing a failed system. "VoIP began another evolution of the PSTN architecture. The PSTN is a large infrastructure that will likely take some time to completely migrate to the next generation of technologies; but this migration process is underway" [11].

In the cellular system, Mobile Telephone Switching Offices (MTSOs), also known as Mobile Switching Centers (MSCs), are very similar to PSTN Central Offices (COs), and they function like class 5 switches [12]. MSCs are connected to the PSTN switching centers through Gateway Mobile Switching Centers (GMSCs), which are a type of MSC, as shown in Fig. 2. The main function of an MSC is to connect mobile telephones to landline telephones or two mobile telephones in the same area, and an "MTSO is supposed to appear as a seamless extension of the public switched telephone network from the customer's perspective" [12]. In fact, both the PSTN and the cellular system use circuit switches made by the same equipment manufacturers, which are very similar.

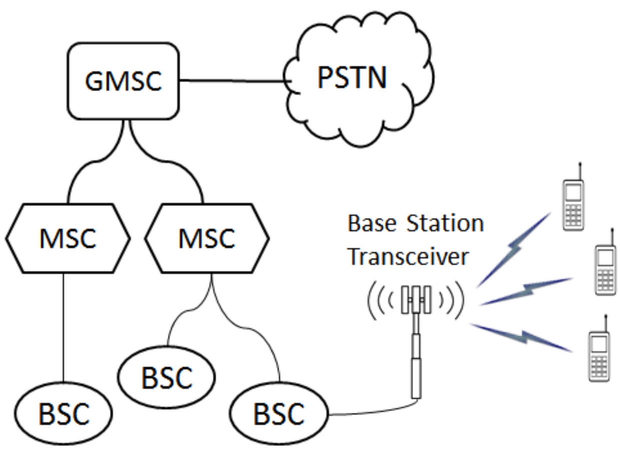

Figure 2. PSTN and mobile network.

As noted from the FCC website, the number of local switches has been slightly decreasing with time. This is partly due to the current migration from the legacy PSTN infrastructure to the more cost effective NGN infrastructure. In fact, at the end of their lifecycle, traditional PSTN Class 4 and Class 5 switches are transformed to media gateways or replaced by VoIP soft switches [13, 14, 15]. Media gateways (also called access servers) interconnect the traditional PSTN to VoIP networks, and they can originate or terminate landline phone calls. Soft switches function as other telephone switches except that they are software installed on servers, and they deal with IP to IP phone calls only. Fig. 3 depicts an interconnection between the traditional PSTN and a VoIP network.

C. *Reliability and Survivability Theories*

The reliability of a system is the probability of that system performing and maintaining its designated functions at an adequate level of performance, under specified circumstances and for a specified period of time [2]. Thresholds are used in specifying adequate levels of performance for repairable systems in order to differentiate operating and failed states [2].

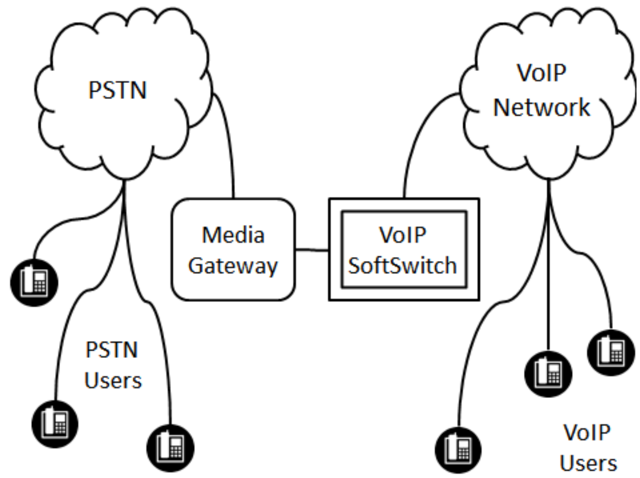

Figure 3. PSTN and VoIP network.

As mentioned before, a repairable system is defined as a system that passes from an operating mode to a failed mode, and back again after a certain period of time by means other than replacing the entire system [2]. A repairable system is also a counting failure process where successive inter-arrival failure times (time-between-failures) will tend to become larger for an improving system or become smaller for a deteriorating system [16]. The reliability of local switches can be assessed by analyzing the nature of failures experienced by those switches.

Point processes have been chosen for modeling the failure times since the time to repair or replace the system (local switches in our case) was negligible compared to its operating time. When the failure rate is constant over time, it can be modeled as a homogeneous Poisson process (HPP), which means that there is no improvement. On the other hand, when the failure rate varies over time, a non-homogeneous Poisson process (NHPP) is a better fit to model either an improving or deteriorating system [2].

The Laplace trend test, a reliability trend test, determines if there is a significant change in the pattern of successive failures of a repairable system over time. In fact, "[the] Laplace test, also known as the centroid test, is a measure that compares the centroid of observed arrival times with the midpoint of the period of observation. This measure approximates the standardized normal random variable (e.g., z-score)" [17]. The reliability trend test for repairable systems assumes the null hypothesis (H_o) to be HPP (no trend) and the alternative hypothesis (H_a) to be NHPP (there is a trend). If the null hypothesis can be rejected at a specified significance level, then it can be concluded that the system is either improving or deteriorating over the timeframe of interest [16]. The Laplace score U is given by the formula [17]:

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$$U = \left[\left(\frac{\sum_i^n t_i}{n}\right) - \frac{T}{2}\right] / T\sqrt{1/12n} \quad (1)$$

where:

t_i is the time (e.g., number of days) from a fixed start point to the time of each event (outage).

n is the number of outage events (if t_n = T, then n-1 is used instead of n in the formula).

T is the time from the start point to the end of the study period.

A positive score implies an upward or increasing trend (i.e., the system is deteriorating), a negative score implies a downward or decreasing trend (i.e., the system is improving), and a null score implies a constant trend (i.e., no change). Furthermore, "[when] the score is greater than (less than) +1.96 (-1.96), we are at least 95% confident that there is a significant trend upward (downward)" [17].

As an example of reliability assessment using the Laplace trend test, consider the failure arrival times given in Table I, where U-scores were calculated using the aforementioned formula. We can see from the table that the first set of sample failure arrival times represents an increasing trend (i.e., reliability deterioration) where the Laplace score U equals +3.46. The second set of sample failure arrival times represents a constant trend (i.e., no change in reliability) because the Laplace score U, which equals +1.79, is neither greater than +1.96 nor less than -1.96. The third set of sample failure arrival times represents a decreasing trend (i.e., reliability growth) where the Laplace score U equals -2.07. Visual representations of the increasing trend, the constant trend and the decreasing trend are given in Figs. 4, 5 and 6 respectively.

TABLE I. LAPLACE SCORE & FAILURE TREND EXAMPLES

Failure Trend Examples	***Increasing***	***Constant***	***Decreasing***
Failure Arrival Times	1	1	1
	8	3.5	1.1
	10	6	1.3
	11.5	8.5	1.8
	12.5	10.5	2.6
	13	13	3.5
Laplace Score (U)	**3.46**	**1.79**	**-2.07**

Survivability is defined as "the capability of a system to fulfill its mission, in a timely manner, in the presence of attacks, failures, or accidents." Typically, for a system to survive, it must automatically react to (and recover from) a harmful incident well before the root cause has been identified [18]. The survivability of local switches can be determined by analyzing the frequency and impact of failures experienced by those switches.

A system is delivering correct service when it is adequately fulfilling its functions. A service failure (or simply a failure) occurs when the system is not adequately implementing its functions, and the period during which the system is delivering incorrect service is called a service outage (or simply an outage) [19]. Failures are incidents that are likely to disturb the system and cause it to deliver incorrect service. They may be caused by deficiencies in the system or by external components to which the system is attached. Failures may be due to such things as software/hardware design errors, human errors, traffic overload, and natural disasters [18].

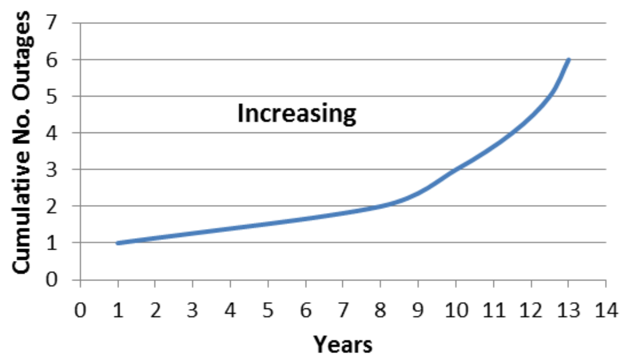

Figure 4. Example of reliability deterioration .

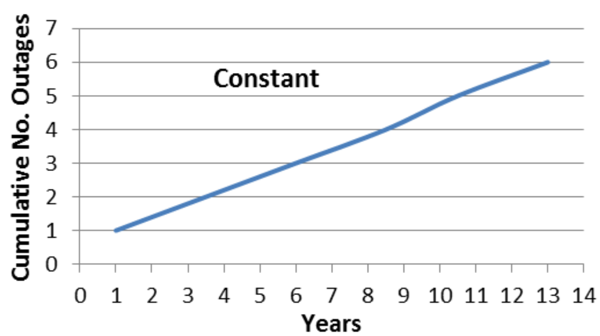

Figure 5. An example of a constant failure trend.

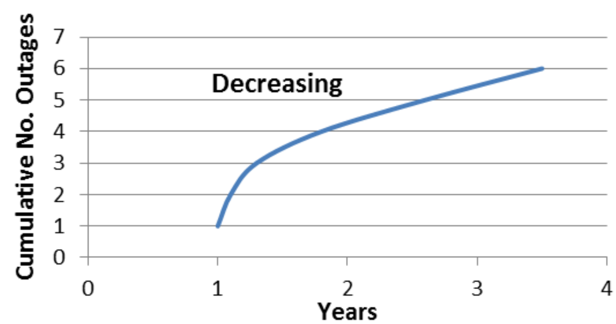

Figure 6. Example of reliability growth (decreasing failure trend).

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Lost line hours, LLH, is an outage impact metric (or communication loss metric) that can be used to assess system survivability. LLH is the product of the number of access lines served by the and the duration of the outage [6]. For example, if a 3,000 access lines switch went down for 20 minutes, the LLH would be 1,000, meaning equivalency with 1,000 lines out for an hour. In this research, the LLH metric has been chosen to assess the survivability of local switches because it is simple and intuitive.

The metric also takes into account the size of the failed switch and the duration of the outage. It does not however account for blocked calls, but that data is not available from the switch outage reports.

D. *The FCC Reporting Systems*

The FCC, established by the Communications Act of 1934, is an independent agency of the US government. It regulates interstate and international communications by radio, television, wire, satellite and cable, and its jurisdiction covers the 50 states, the District of Columbia, and other US territories [20].

Until 2009, all US Local Exchange Carriers (LECs) reported each telecommunication switch outage of two minutes or more to the ARMIS (Automated Reporting Management Information System) section of the FCC website. Those public reports are part of FCC Report 43-05, the ARMIS Service Quality Report [21]. Note that the two-minute ARMIS reporting limit is used as the reliability threshold in this study. Again note that only totally failed switches were reported. The switch population required to report by LECs account for over 90% of the landline telephone access lines in the US [3].

ARMIS was initiated in 1987 to collect financial and operational data from the largest carriers in the US. Later in 1991, additional ARMIS reports were added to collect service quality (i.e., the FCC Report 43-05) and network infrastructure information from all US LECs subject to price cap regulations. However, after 2009, the FCC stopped collecting Report 43-05 as stated in the ARMIS Forbearance Order, where

> The Commission granted conditional forbearance from carrier obligations to file ARMIS Reports 43-05 and 43-06 provided that the carriers committed to file the data voluntarily for 24 months after September 6, 2008. The 24 months ended on September 6, 2010; and carriers do not file Reports 43-05 and 43-06 for reporting year 2010 and subsequent years [21].

The reports submitted to ARMIS contain information on each failed switch, including the date, time of outage occurrence, number of lines supported, outage duration, and outage cause. Additionally reported items include whether the switch is located in a Metropolitan Statistical Area (MSA = urban area) or not (Non-MSA = rural area), COSA (Company Operating company Study Area), and the switch CLLI code (Common Language Location Identifier). CLLI codes are unique identifiers for individual local switches. Carriers reported outage cause using one of fifteen different cause codes created by the FCC. In this study, cause code 1 is a scheduled maintenance outage; while cause codes 2 through 15 are considered failures, resulting in an outage. All 15 cause codes are defined in Section V.

III. RESEARCH GOALS AND OBJECTIVES

For a system to be properly improved it is necessary to know its past state and performance. Hence, from this perspective, monitoring the performance and assessing the reliability of local switches during past years will help understand what caused the outages to occur, and thus take corrective/preventive actions to alter future trends. Preliminary data exploration reveals a small number of switches or more outages an appreciable percent of all switch outages. The principal goal of this research is to compare the outage causality and switch characteristics between more frequently failing local switches and less frequently failing local switches. As its objective, this research focuses on addressing the following questions concerning local switches performance over a study period of 14 years:

A. *Research Questions*

1. What are the major causes of local telecommunication switch outages?
2. Is the reliability of local switches improving, constant, or deteriorating?
3. Are there individual switches that experience outages/failures more so than others?
4. Are there similarities/dissimilarities between switches failing more often and those that do not? In terms of:
    a. LLH
    b. Rural versus Urban
    c. Outage causes
    d. Outage duration
    e. Time of Day (TOD)
    f. Day of Week (DOW)
    g. Month of Year (MOY)
    h. Outage/failure trends
5. Are there switch manufacturers that account for outages/failures more so than others?

IV. METHODOLOGY

A. *Research Data*

The data used in this study were drawn from the FCC's ARMIS website (http://transition.fcc.gov/wcb/armis/) where US LECs reported switches that experienced a downtime of two minutes or more, and the data cover a 14-year period (from 1996 to 2009). The data include different information on the failed switches such as date, week day and time when the outages occurred, number of lines supported by the switches, duration and cause of the outages, MSA, COSA, and CLLI codes. Fifty-nine records were removed due to errors in recording the data, which left a total of 12,860 records.

In order to conduct research on frequently failing local switches, ARMIS data has been augmented by data from TelcoData.us, where additional information on US telecommunication switches is provided, such as switch models/manufacturers, and switch locations [22]. The Local Calling Guide website also provides information on US local switches, and was used to verify data from TelcoData.us and match these data to data from ARMIS [23].

B. Data Analysis Methods

The frequency of outage causes has been analyzed to assess the reliability of local switches, and the impact of those outage events has been analyzed to assess switch survivability. In order to assess differences that might exist in local telecommunication switch outages, the data have been separated into two categories: more frequently failing switches (8 or more outages over the study period) and less frequently failing switches (7 or less outages over the study period). The reliability difference between categories has been investigated by comparing failure trends and Laplace scores. Likewise, the survivability difference has been investigated by comparing impact trends and their respective LLH values.

In this study two measures of central tendency have been used to compare the two categories of data: the mean and the median. The t-Test (Two-Sample Assuming Unequal Variances) has been used to determine whether any difference between the means in the two local switch categories is statistically significant. We assumed that the two data sets came from distributions with unequal variances because one data set is considerably larger than the other one. Acts of god include such circumstances as wind, flooding, and earthquake.

For the t-Test, the null hypothesis (H_o) is that the means are the same, while the alternative hypothesis (H_a) is that the means are different.

V. RESEARCH RESULTS ANALYSIS

A. Causes of Local Telecommunication Switch Outages

As mentioned earlier, the cause of each reported outage was classified by carriers using 15 different cause codes. An abbreviated definition of each cause code together with the total number of reported outages for each are shown in Table II. The outage distribution is also shown in Fig. 7. From this table, two causes account for over 50% of the local switch outages:

- *Scheduled* outages (cause code 1)
- *Random hardware failure* (cause code 8)

Scheduled outages are planned for short duration, and therefore have little impact on the PSTN users because they are scheduled during hours and days of low traffic on the PSTN network. On the contrary, failures resulting in outages are unpredictable, occurring at any time and any day, impacting PSTN users in many cases. For that reason, it is also important to investigate the major causes of failures in PSTN local switches.

By discounting scheduled outages (cause code 1) and looking at failed switches (cause codes 2 to 15), we note from Table III that the main sources of failures in local switches account for almost 2/3 of all failures:

- *Hardware failures* (cause code 8)
- *Software design errors* (cause code 6)
- *Acts of God* (cause code (9)
- *External power failures* (cause code 12)

Tables III and IV give detailed information on the causes of local telecommunication switch outages; where Table IV consolidates cause codes to provide insights into major causal categories.

In this paper, major cause codes have been categorized as follows:

- *Scheduled Outages* (Cause Code 1): scheduled or planned maintenance activities.
- *Human Procedural Errors* (Cause Codes 2 to 5): installation/non-installation and maintenance/non-maintenance related errors made by the operating company technicians, or other errors made by system vendors or other vendors.
- *Design Errors* (Cause Codes 6 and 7): errors made by system vendors in designing the software or
- *Hardware Failures* (Cause Code 8): other hardware failures except design errors.
- *External Circumstances* (Cause Codes 9 to 14): other events, but external to the switch, which cause the switch to fail.
- *Others/Unknown* (Cause Code 15): all other events, different from the above, that cause the switch to fail.

TABLE II. OUTAGE DISTRIBUTION BY CAUSE

Cause Code	Description	No. Outages	%
1	Scheduled	3,885	30.2%
2	Procedural error (Telco install./maint.)	446	3.5%
3	Procedural error (Telco non-install./non-maint.)	376	2.9%
4	Procedural error (System vendor procedural error)	315	2.4%
5	Procedural error (Other vendor procedural error)	257	2.0%
6	Software design	1,078	8.4%
7	Hardware design	136	1.1%
8	Hardware failure	2,951	22.9%
9	Acts of God	935	7.3%
10	Traffic overload	17	0.1%
11	Environmental	83	0.6%
12	External power failure	896	7.0%
13	Massive line outage, cable cut, other	660	5.1%
14	Remote (Loss of facilities between host and remote)	309	2.4%
15	Other/unknown	516	4.0%
	Total	**12,860**	**100%**

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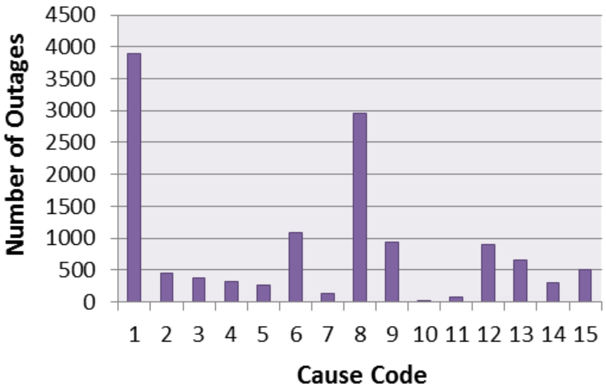

Figure 7. Local switch outage distribution.

TABLE III. FAILURE DISTRIBUTION BY CAUSE

Cause Code	Description	No. Outages	%
2	Procedural error (Telco install./maintenance)	446	5.0%
3	Procedural error (Telco non-install./non-maintenance)	376	4.2%
4	Procedural error (System vendor procedural error)	315	3.5%
5	Procedural error (Other vendor procedural error)	257	2.9%
6	Software design	1,078	12.0%
7	Hardware design	136	1.5%
8	Hardware failure	2,951	32.9%
9	Acts of God	935	10.4%
10	Traffic overload	17	0.2%
11	Environmental	83	0.9%
12	External power failure	896	10.0%
13	Massive line outage, cable cut, other	660	7.4%
14	Remote (Loss of facilities between host and remote)	309	3.4%
15	Other/unknown	516	5.7%
	Total	8,975	100%

TABLE IV. LOCAL SWITCH FAILURE DISTRIBUTION BY CATEGORY

Cause Code Category	No. Outages	%
Human Procedural Errors (2-5)	1,394	15.5%
Design Errors (6-7)	1,214	13.5%
Hardware Failures (8)	2,951	32.9%
External Circumstances (9-14)	2,900	32.3%
Others/Unknown (15)	516	5.7%
Total	8,975	100%

The percentage distribution of outages among the different cause code categories is shown in Table IV. It can be seen that scheduled outages (about 30% of all outages), hardware failures (about 23% of all outages) and external circumstances (also about 23% of all outages) are the main cause categories of local telecommunication switch outages. Table IV indicates that after hardware and external circumstances, procedural and design errors account for 29% of failures.

B. *Reliability Trends of Local Switches*

The outage rate of local switches can give us insight into reliability trends. As mentioned before, the variation of the outage rate over time implies a NHPP, which allows us to determine whether the system has been improving or deteriorating. Again, Laplace scores greater than 1.96 and less than -1.96 indicate strong statistical evidence of an increasing or decreasing trend, respectively.

A cumulative time series graph of all outages occurring over the 14-year study period is shown in Fig. 8.

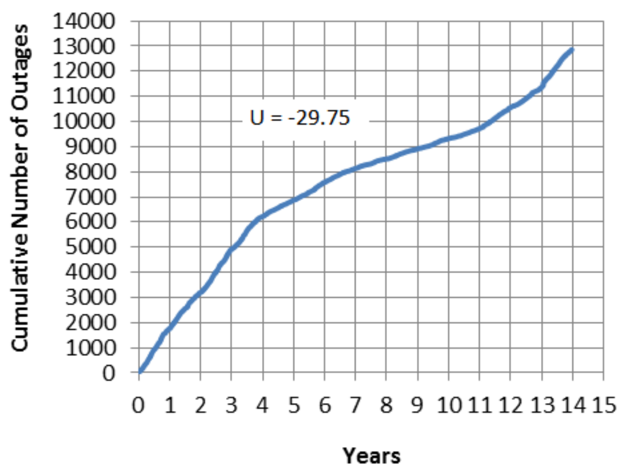

Figure 8. Switch reliability trend (all cause codes).

The figure, as well as the accompanying Laplace score (U = -29.75), show that, overall, there has been exceptionally strong reliability growth over the study period. However, there also seems to have been periods of reliability growth and periods of reliability deterioration along the study period. For example, the reliability was relatively constant from the start of the study period until the end of year 4; then it improved from year 5 until the end of year 11; subsequently, the trend started bending upwards towards the end of the study period (from year 12), which means that the reliability was starting to deteriorate.

By separating failures from scheduled outages we can gain a clearer picture of local switch reliability improvement. The reliability trend, considering only the scheduled outages, is shown in Fig. 9. From the figure, as well as from the accompanying Laplace score (U = -58.41), we conclude remarkably strong reliability growth, especially from year 5 (i.e., 2000). These switches have “A” and “B” processors, one of which is primary and the other a live backup. Early in the study period vendors/carriers took the entire switch down for software/feature changes, resulting in short outages. Towards the end of the study period, one processor was taken down at a time for upgrade, and switch continued operating with many fewer outages..

On the other hand, from Fig. 10, which shows failures (all outages other than those that were scheduled), we notice a statistically significant reliability decrease (U = 2.81).

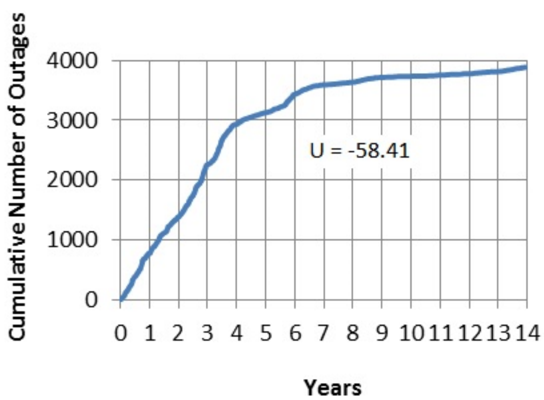

Figure 9. Switches reliability trend (Scheduled: cause code 1).

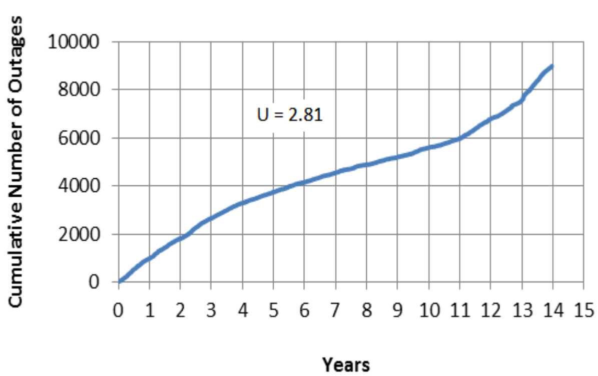

Figure 10. Switch reliability trend (Failures: cause codes 2-15).

This means that the switches have been failing more and more often due to increasing failures for the last three years of the study period. Therefore, by combining the two trends, one from scheduled outages and the other one from failures that resulted in outages, we get a trend that shows an overall reliability improvement in local switches from 1996 to 2009, but interesting insights are gained by separating scheduled outages and failure-induced outages.

C. *More Frequently Failing Switches Analysis*

There are many switches that failed more than once during the 14-year study period. A logarithmic chart of the number of outages encountered by failed switches during the study period is shown in Fig. 11. A total of 6,132 local switches have been responsible for 12,860 outages. The failed switches can be divided into two categories according to the number of outages that each unique switch encountered during the study period. In fact, 5,976 unique switches (about 97% of all switches) experienced 7 outages or less (which made about 80% of all outages); while 156 unique switches (about 3% of all switches) experienced 8 or more outages (which made about 20% of all outages) during the study period. The choice to focus on 8 or more outages was influenced by the fact that the curve from 1 outage to 8 outages in Fig. 11 was smooth and started to become irregular from 9 outages and up.

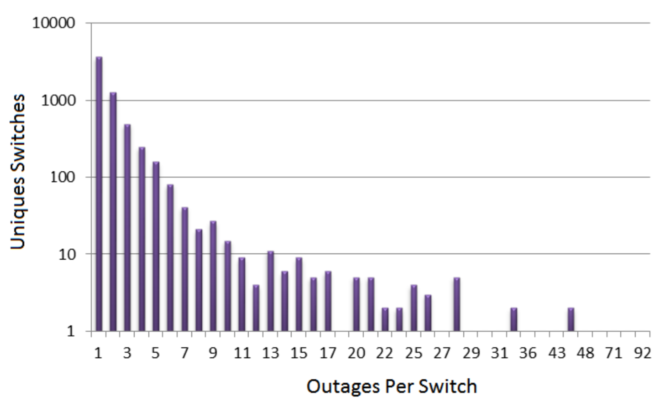

Figure 11. Unique local switch outage frequency (logarithmic scale).

Indeed, the more frequently failing switches account for only 3% of all individual switches failing over the study period. However, those 3% of the individual switches caused 20% of all outages that occurred.. From a survivability perspective, even if the more frequently failing switches caused 20% of all outages, they are responsible for only 7% of all LLH. Additionally, these more frequently failing switches are responsible for 9% of all lines down during the study period, and those lines out account for 22% of the total outage duration (more details are shown later in Table V).

As Fig. 11 uses a logarithmic scale in presenting the number of switches, instances of 1 switch having numerous outages is not indicated. Those instances are in Table V, where it is seen that remarkably, five different switches experienced 92, 75, 71, 60, and 48 outages. Additionally, two different switches both experienced 47 outages.

D. *Frequently and Less-Frequently Failing SwitchComparisons*

As mentioned earlier, the local switches have been divided into two categories, one of less frequently failing switches and another one of more frequently failing switches. Comparisons are made between impact (LLH), switch location (rural or urban), outage cause codes, outages duration, time of day, day of week and month of year, and outage trends.

Each switch that fails has an impact on customers connected to that switch. A large switch (i.e., that has many lines connected to it) can go down for few minutes and still have the same impact as a small switch that goes down for many minutes. That is why the LLH metric is the best means to assess the impact of many different outages pooled together because it gives only one value, which is the product of the number of lines supported by the failed switch and the duration of the outage.

TABLE V. UNIQUE SWITCH OUTAGE FREQUENCY OVER 14 YEARS

No. Outages	No. Unique Switches	No. Outages	No. Unique Switches
1	3,701	22	2
2	1,259	23	2
3	489	25	4
4	247	26	3
5	158	27	1
6	81	28	5
7	41	29	1
8	21	30	1
9	27	31	1
10	15	32	2
11	9	36	1
12	4	40	1
13	11	43	1
14	6	47	2
15	9	48	1
16	5	60	1
17	6	71	1
18	1	75	1
20	5	92	1
21	5		

Before comparing the two categories of switches that experienced outages during the study period, let us have a look at the total LLH per year that resulted from all outages that occurred during the study period. We can see from Fig. 12 that there have been higher survivability deficits in 2001, 2005, and 2007. The figure also shows that the majority of outages were due to cause codes other than cause code 1, which is scheduled outage.

The high survivability decrease in 2001 is related to the 9/11 attacks in New York City since 77% (about 33,400,000 LLH) of the 2001 total LLH resulted from five switches located in New York, on September 11, 2001. Furthermore, the high survivability decrease in 2005 appears to be due to the 2005 Atlantic hurricane season, “the most devastating hurricane season the country has experienced in modern times,” [25] as 97% of the 2005 LLH occurred during the hurricane season, which begins June 1st and ends November 30th. The 2005 Atlantic hurricane season’s strongest hurricanes include hurricanes Wilma and Katrina. Similarly, the survivability decrease in 2007 appears to be due to the 2007 Atlantic hurricane season as 69% (about 47,000,000 LLH) of the 2007 LLH resulted from outages occurring during hurricane season. The 2007 Atlantic hurricane season’s strongest hurricane was hurricane Dean.

A LLH comparison for each local switch category during the study period is given in Fig. 13. It is seen that the more frequently failing switches account for a very small portion of the impact on the PSTN.

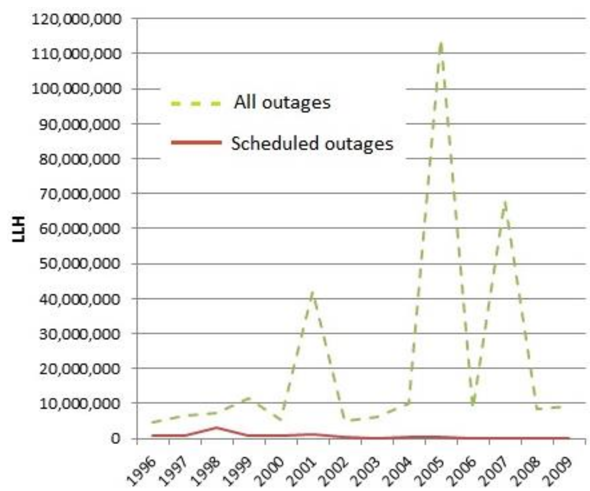

Figure 12. LLH per year for all versus scheduled outages.

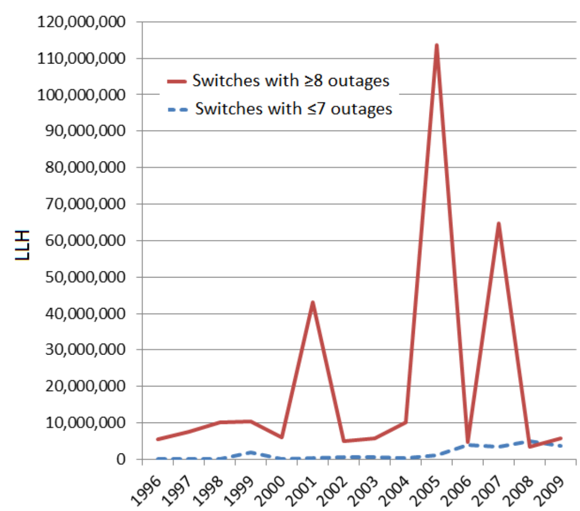

Figure 13. LLH per year for frequent/infrequectly out switches.

As for the 8 or more outages category (shown more clearly by Fig. 14), there have been two major survivability deficits along the 14-year study period. The first one occurred in 1999 where the LLH count reached almost 2,000,000 lines hours. The second and longest survivability decrease started in 2005 and continued until 2008 where it started to increase. There has been a slight survivability increase in 2007 but it was nothing compared to the survivability decrease that preceded in 2006 and the one that

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followed in 2008. During this deterioration period, the highest LLH count reached almost 5,000,000 lines hours. The reason for the peaks is not discernible from the data.

A comparison of the number of outages/year experienced by switches in both categories, taking into account whether they are located in urban or rural areas, is shown in Figs. 15 and 16. In both categories rural switches suffered outages more often than urban switches.

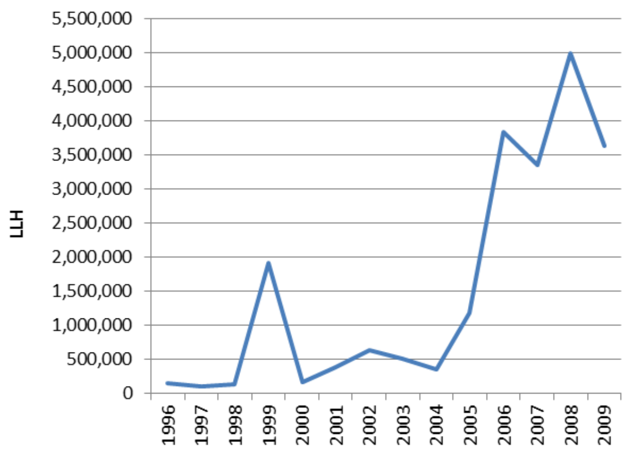

Figure 14. LLH per year for switches out ≥8 times.

From Fig. 15 we can see switches or more outages 7 outages or less had most of its outages at the start of the study period, from both rural and urban switches. On the other hand, switches or more outages 8 or more outages had most of its outages towards the end of the study period, mostly from rural switches (Fig. 16).

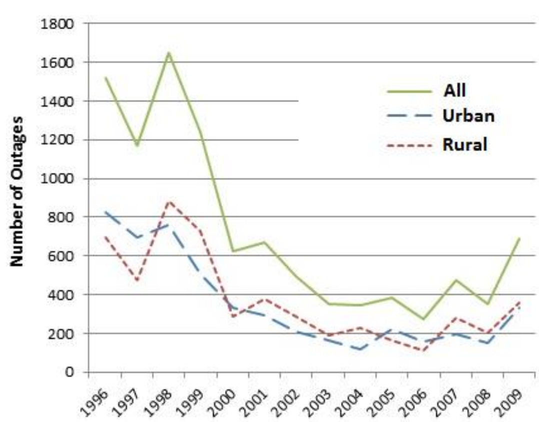

Figure 15. Urban vs rural switch outages per year (≤ 7 outages per switch)

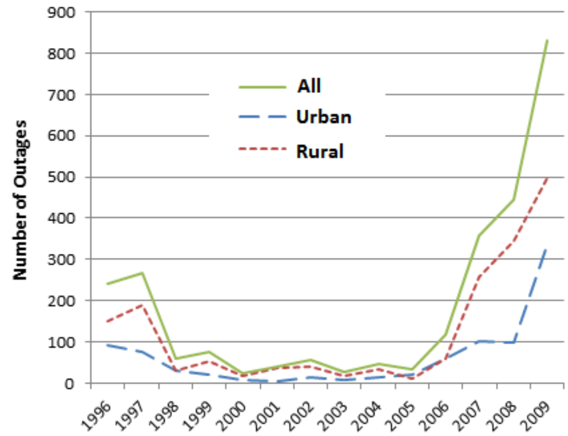

Figure 16. Urban vs. rural switch outages per year (≥8 outages per switch)

A comparison of the cause code frequency in both categories is shown in Fig. 17. Note that the switches that experienced 7 outages or less suffered considerably from scheduled outages (cause code 1) more often than the switches that experienced 8 or more outages. On the other hand, the switches that experienced 8 or more outages considerably suffered from hardware failures (cause code 8) and acts of God (cause code 9) more often than the switches in the other category.

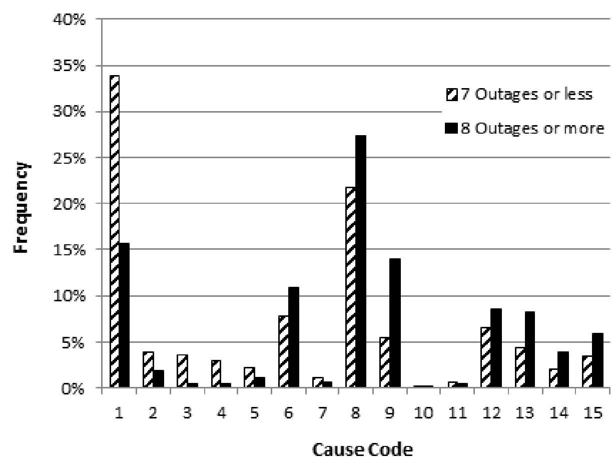

Figure 17. Outage cause code frequency.

By categorizing cause codes, we see from Fig. 18 that switches experiencing 8 or more outages suffered from design errors, random hardware failures, external circumstances and other/unknown causes more often than the switches experiencing 7 outages or less. Those failures might be the consequence of insufficient maintenance activities for the more frequently failing switches since most are located in rural areas. It is most interesting that the less frequently failing switches suffered a higher percentage of outages due to human procedural errors (Fig. 18).

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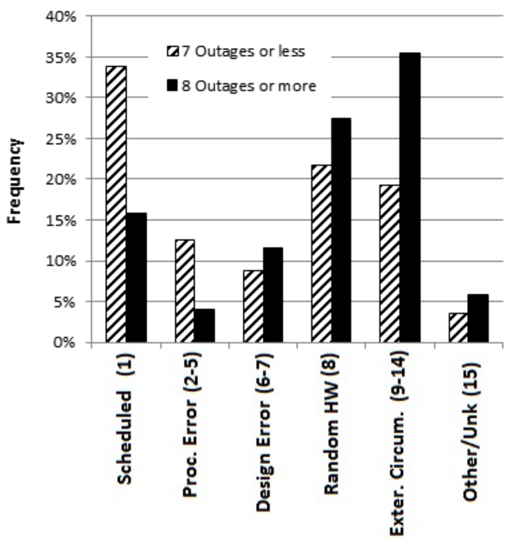

Figure 18. Causal Category frequency distribution.

Outages can be examined for all causes, scheduled causes, and failures. For each of these cases, the two outage frequency categories can also be compared.

1) Outages from all Causes

A numerical comparison between the two outage frequency categories, for all outage causes, is given in Table VI. Again, note that even if the switches experiencing 8 or more outages represent only 3% of all unique switches that failed during the 14-year study period, they are responsible for 20% of all outages that occurred. Additionally, those more frequently failing switches are responsible for 9% of all lines that went down during the study period, which corresponds to 22% of the total down time, in addition to 7% of the total LLH. Although the average duration values are roughly equal in both categories (3.6 and 3.2 hours per outage), the average LLH values are considerably different (8,129 and 28,890 LLH per outage) because the more frequently failing switches are in most cases smaller switches.

2) Scheduled Outages

A numerical comparison between the two outage frequency categories for scheduled outages is given in Table VII. In this case, the more frequently failing switches represent 3% of all unique switches that went down due to scheduled maintenance activities, which made 11% of all scheduled outages that occurred during the 14-year study period. Those more frequently failing switches are also responsible for 7% of all lines that went down due to scheduled maintenance activities during the study period, which corresponds to 21% of the total down time and hence 9% of the LLH due to scheduled maintenance activities. Also notice that average duration and average LLH for both categories are approximately equal.

TABLE VI. OUTAGE CHARACTERISTICS COMPARISON

All Cause Codes	All Outages	≥ 8 Outages	≤ 7 Outages	% ≥ 8	%≤ 7
No. of Outages	12,860	2,623	10,237	20%	80%
No. of Switches	6,132	156	5,976	3%	97%
Tot. Switch Lines Out	123.2 M	10.5 M	112.7 M	9%	91%
Tot. Dur. (Hours)	42,391	9,443	32,947	22%	78%
Total LLH	317.1 M	21.3 M	295.8 M	7%	93%
Avg. Switch Size (Lines)	9,584	4,040	11,005		
Avg. Dur. (Hours)	3.3	3.6	3.2		
Avg. LLH	24,655	8,129	28,890		
Median TOD	10:14am	11:38am	9:51am		
Mean TOD	10:55am	11:41am	10:43am		
Median DOW	4.13	4.36	4.11		
Mean DOW	4.27	4.37	4.25		
Median MOY	6.89	6.98	6.89		
Mean MOY	6.92	6.90	6.93		
Med. MSA No=Rural	No	No	No		

TABLE VII. SCHEDULED OUTAGE COMPARISON

Cause Code 1	All Outages	≥ 8 Outages	≤ 7 Outages	% ≥ 8	% ≤ 7
No. of Outages	3,885	413	3,472	11%	89%
No. of Switches	2,470	86	2,384	3%	97%
Tot. Switch Lines Out	57.6	4.0 M	53.6 M	7%	93%
Tot. Dur. (Hours)	998	211	787	21%	79%
Total LLH	9.2 M	0.9 M	8.3 M	9%	91%
Avg. Switch Size(Lines)	14,830	9,605	15,451		
Avg. Dur. (Hours)	0.3	0.5	0.2		
Avg. LLH	2,385	2,093	2,420		
Median TOD	5:47am,	4:37am	6:00am		
Mean TOD	10:38am	10:32am	10:39am		
Median DOW	4.18	5.03	4.16		
Mean DOW	4.40	4.68	4.36		
Median MOY	6.92	6.56	6.97		
Mean MOY	7.04	6.89	7.06		
Med. MSA (No=Rural)	No	No	Yes		

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3) *Outages Due to Failures*

A numerical comparison between the two outage frequency categories, due to failures (cause codes 2-15) is in Table VIII. In this case, the more frequently failing switches still represent only 3% of all unique failed switches resulting in outages, but they caused 25% of all failures occurring. Those more frequently failing switches are also responsible for 10% of all lines that went down, which corresponds to 22% of the total down time, and hence 7% of the total LLH. Also notice that even if the average duration in both categories are roughly equal, the average LLH per switch are very different (9,257 vs. 42,475 LLH).

The t-Test results are given in Table IX. Again, a significance level of 0.05 has been used. Significant temporal differences between frequently out and less frequently out switches are apparent.

E. *Local Switch Outage and Failure Trends*

The outage trends of local switches in both categories during the 14-year study period, taking into consideration all cause codes, are shown in Figs. 19 and 20.

TABLE VIII. FAILURE CHARACTERISTICS COMPARISON

Cause: Codes 2-15	All Outages	≥ 8 Outages	≤ 7 Outages	% ≥ 8	% ≤ 7
Number Outages	8,975	2,210	6,765	25%	75%
Number Switches	4,517	154	4,363	3%	97%
Tot. Switch Lines	65.6 M	6.6 M	59.0 M	10%	90%
Tot. Dur. (Hours)	41,393	9,232	32,160	22%	78%
Total LLH	307.8 M	20.5 M	287.3 M	7%	93%
Avg. Switch Size	7,313	3,000	8,723		
Avg. Dur. (Hours)	4.6	4.2	4.8		
Avg LLH	34,295	9,257	42,475		
Median TOD	10:57am	12:00pm	10:34am		
Mean TOD	11:02am	11:54am	10:45am		
Median DOW	4.09	4.29	4.06		
Mean DOW	4.22	4.32	4.19		
Median MOY	6.89	7.08	6.82		
Mean MOY	6.87	6.90	6.86		
Med. MSA (N=Rural)	N	N	N		

TABLE IX. TEMPORAL T-TEST RESULTS

t-Test (MEANS)	≥ 8 Outages	≤ 7 Outages	Difference	P-value (one-tail)
TOD All Codes	11:41 am	10:44 am	YES	0.000
TOD Scheduled	10:32 am	10:40 am	NO	0.400
TOD Failures	11:54 am	10:46 am	YES	0.000
DOW All	4.37	4.25	YES	0.001
DOW Scheduled	4.68	4.36	YES	0.000
DOW Failures	4.32	4.19	YES	0.003
MOY All	6.90	6.93	NO	0.335
MOY Scheduled	6.89	7.06	NO	0.146
MOY Failures	6.90	6.86	NO	0.322

For the switches that experienced 7 outages or less, we can see from Fig. 19, as well as from the accompanying Laplace score (U = -48.66), that there has been steady reliability growth from the start of the study period until the end of the study period.

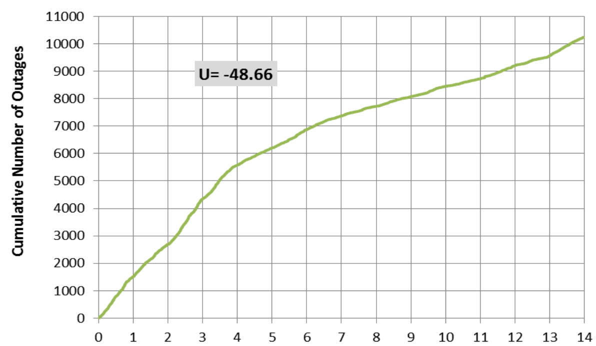

Figure 19. Outage trend for switches with ≤ 7 outages.

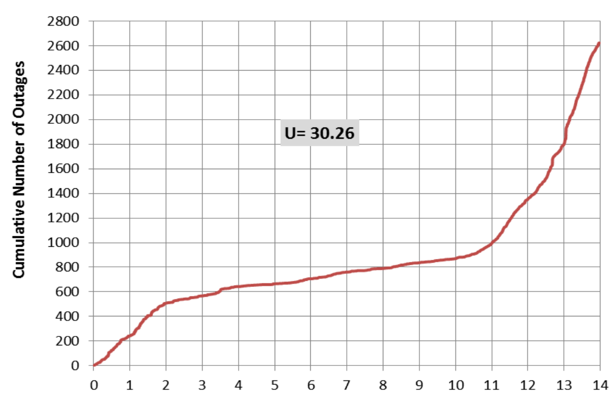

Figure 20. Outage trend for local switches or more outages ≥8 outages.

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However, for the switches that experienced 8 or more outages, we can see from Fig. 20, as well as from the accompanying Laplace score (U = 30.26), that the reliability has exhibited dramatic deterioration. However, there seem to have been periods of strong reliability growth and deterioration during the study period. In order to gain more insight into the causes of the outage trend for switches that experienced 8 or more outages along the study period, the outage trend has been divided into three regions as follows:

- 0 ≤ Region I < 2 years
- 2 years ≤ Region II < 11 years
- 11 years ≤ Region III < 14 years

The outage trend of more frequently failing switches divided into regions and considering all the cause codes is shown in Fig. 21. From the figure we can see that the reliability was constant in Region I (U = -0.29) from 1996 to 1997; it then slightly decreased in Region II (U = 3.22) from 1998 to 2006; and finally things got worse in Region III where the reliability sharply decreased (U = 11.84) from 2007 to 2009.

The number of outages per cause code that occurred in each region is shown in Table X. We can see from the table that most of the outages occurred in Region III (62% of all outages in all regions). We can also note from the table that most of the outages in Region I resulted from cause code 1 (scheduled outages) and cause code 6 (software design); most of the outages in Region II resulted from cause codes 1 and 8 (hardware failures), and most of the outages in Region III resulted from cause codes 8 and 9 (acts of God).

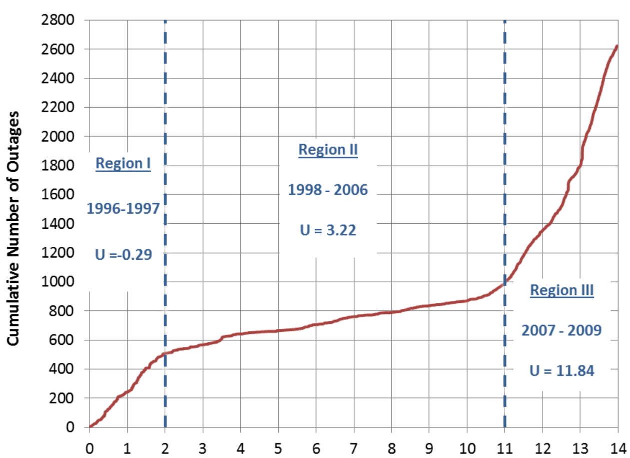

Figure 21. Trend analysis for local switches or more outages ≥8 outages.

By combining the cause codes in categories we can see from Table XI that the major causes of outages in Region I are scheduled outages and design errors; the major causes of outages in Region II are external circumstances, hardware failures and scheduled outages; and the major causes of outages in Region III are external circumstances and hardware failures.

TABLE X. OUTAGE FREQUENCY BY CAUSE CODE FOR MORE FREQUENTLY FAILING SWITCHES IN REGIONS

Cause Code	All No.	%	Reg. I No.	%	Reg. II No.	%	Reg. III No.	%
1	413	15.7	253	49.8	95	19.5	65	4.0
2	49	1.9	5	1.0	24	4.9	20	1.2
3	12	0.5	1	0.2	5	1.0	6	0.4
4	14	0.5	1	0.2	7	1.4	6	0.4
5	30	1.1	1	0.2	8	1.6	21	1.3
6	284	10.8	213	41.9	52	10.7	19	1.2
7	19	0.7	3	0.6	3	0.6	13	0.8
8	718	27.4	26	5.1	112	23.0	580	35.6
9	368	14.0	0	0.0	21	4.3	347	21.3
10	4	0.2	0	0.0	1	0.2	3	0.2
11	14	0.5	0	0.0	3	0.6	11	0.7%
12	224	8.5	4	0.8	41	8.4	179	11.0%
13	215	8.2	1	0.2	61	12.6	153	9.4%
14	104	4.0	0	0.0	41	8.4	63	3.9%
15	155	5.9	0	0.0	12	2.5	143	8.8%
Total	**2,623**	**100**	**508**	**100**	**486**	**100**	**1,629**	**100%**
Pcnt..	**100%**		**19.4%**		**18.5%**		**62.1%**	

Note that the number of scheduled outages considerably decreased from Region I to Region III. Perhaps that is the reason why the number of outages resulting from hardware failures and external circumstances considerably increased from Region I to Region III, as the switches received maintenance.

TABLE XI. OUTAGE FREQUENCY BY CAUSE CATEGORY FOR MORE FREQUENTLY FAILING SWITCHES IN REGIONS

Cause Category	All No.	%	Region I No.	%	Region II No.	%	Region III No.	%
Sched. (1)	413	15.7	253	49.8	95	19.5	65	4.0
Proc. Err (2-5)	105	4.0	8	1.6	44	9.1	53	3.3
Design Err.(6-7)	303	11.6	216	42.5	55	11.3	32	2.0
Hdw (8)	718	27.4	26	5.1	112	23.0	580	35.0
Ext. Circum. (9-14)	929	35.4	5	1.0	168	34.6	756	46.4
Other (15)	155	5.9	0	0.0	12	2.%	143	8.8
Total	**2,623**	**100**	**508**	**100**	**486**	**100**	**1,629**	**100**

The outage trends of local switches in both categories during the 14-year study period, for scheduled outages , are shown in Figs. 22 and 23. For the switches that experienced 7 outages or less, we can see from Fig. 22, as well as from the accompanying Laplace score (U = -56.03), that the reliability strongly improved during the study period. This means that there have been less and less scheduled maintenance activities in those switches along the study period.

For the switches that experienced 8 or more outages, we can see from Fig. 23, as well as from the accompanying Laplace score (U = -16.67), that the reliability in those switches also improved during the study period. In fact, the reliability has been constant from the start of the study period until year 11, but with a high outage rate from the start to year 2 (around 125 outages per year) and then a low outage rate from year 3 to year 11 (around 11 outages per year). The overall reliability growth was moderate because the switches seemed to have had a short period of reliability deterioration at the end of the study period (from year 12 to the end). This means that there have been more scheduled maintenance activities during the last few years of the study period.

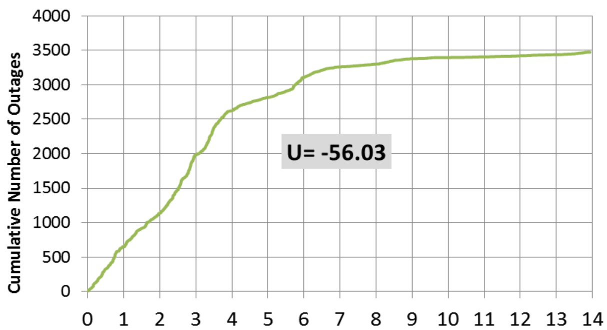

Figure 22. Scheduled outage trend for switches with ≤ 7 outages.

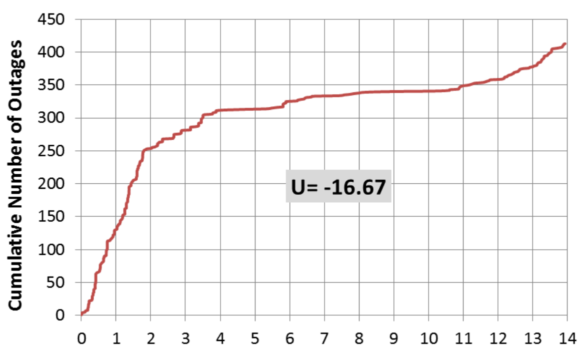

Figure 23. Scheduled outage trend for switches with ≥8 outages.

The failure trends of local switches in both categories during the 14-year study period, for failures (cause codes 2-15) are shown in Figs. 24 and 25. For the switches that experienced 7 outages or less, we can see from Fig. 24, as well as from the accompanying Laplace score (U = -19.72), that there has been steady reliability growth from the start of the study period until the end of the study period, with exception of last year.

In general, the more frequently failing switches showed a serious reliability deterioration, for cause codes 2-15 over the study period as shown by the Laplace score (U = 40.17). For the switches that experienced 8 or more outages, we can see from Fig. 25 that the reliability seemed to improve from the start of the study period to year 11, and then it extremely deteriorated from year 12 until the end of the study period.

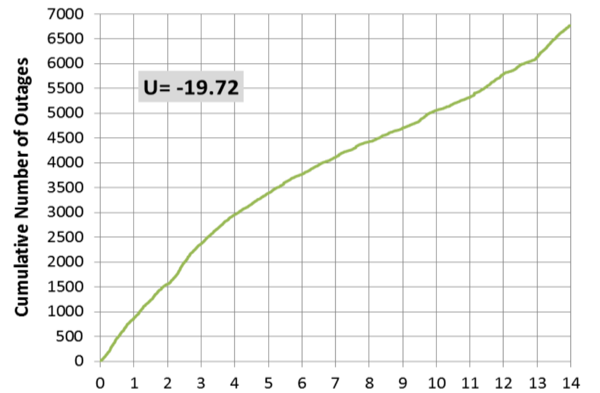

Figure 24. Failure trend for switches with ≤7 outages.

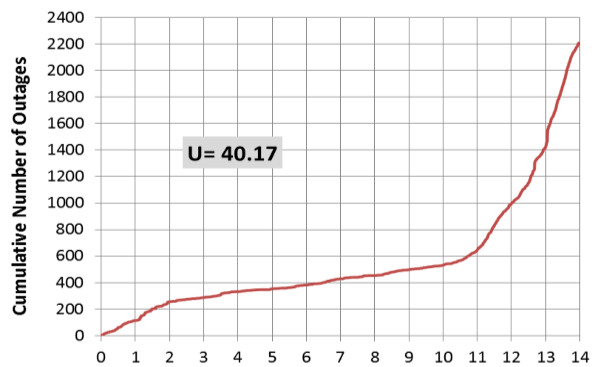

Figure 25. Failure trend for switches with≥ 8 outages.

F. Manufacturers of More Frequently Failing Local Telecommunication Switches

This section discusses the manufacturers of local switches or more outages 8 or more outages during the 14-year study period. As the percentages of switches by manufacturer in the total switch population are unknown, this presentation in this ection is of interest, but not a conclusive assessment.

The 156 unique switches that compose the 8 or more outages were classified among 25 different switch models, then aggregated into outages per manufacturer. There are indeed some switch models that account for the majority of outages. Here however, the 156 unique switches with 8 or more outages are classified among seven different switch manufacturers. The Northern Telecom switches are the ones that failed the most (about 38% of all outages) as shown in Table XII. The Automatic Electric and Ericsson switches come at the second place with roughly equal percentages of about 19% each. Lucent technology switches represent a very low percentage of the frequently out switches. Northern Telcom and Lucent switches are the most prolific in the switch population. The age of switches was not reported, however, we would expect older switches to have more random hardware outages.

TABLE XII. SWITCH MANUFACTURER OUTAGE FREQUENCY FOR MORE FREQUENTLY FAILING SWITCHES

Switch Manufacturer	Outage Frequency (No. of Outages)		No. Unique Switches	
Northern Telecom	999	38.1%	57	36.5%
Automatic Electric	505	19.3%	25	16.0%
Ericsson	493	18.8%	35	22.4%
Stromberg Carlson	264	10.1%	16	10.3%
Siemens	193	7.4%	9	5.8%
Unknown	130	5.0%	11	7.1%
Lucent Technologies	39	1.5%	3	1.9%
Total	**2623**	**100 %**	**156**	**100%**

VI. RESEARCH FINDINGS AND CONCLUSION

A. *Research Findings*

The research findings are presented for each research question, in the order presented earlier:

1) What are the major causes of local telecommunication switch outages?

In general, the major causes of local telecommunication switch outages between 1996 and 2009 were scheduled maintenance activities (i.e., scheduled outages) and hardware failures. When considering only failure induced outages, most local switch failures resulted from hardware failures, software design errors, acts of God and external power failures.

2) Is the reliability of local switches improving, constant, or deteriorating?

In general, the reliability of local switches has been improving over the study period. However, significant deterioration towards the end of the study period is very apparent. Also, when scheduled outages are discounted, the outage trend due to switch failures dramatically increased.

3) Are there individual switches that experience outages/failures more so than others?

Only 3% of all individual switches experiencing outages were responsible for 20% of all outages and 22% of the total downtime. These more frequently failing switches encountered eight or more outages each during the study period.

4) Are there similarities/dissimilarities between switches failing more often and those that do not?

a) Impact of Outages

Over the 14 years study period, scheduled outages had little apparent impact. Three years in particular (2001, 2005, and 2007) account for the lion's share of impact due to switch failures. The year 2001 corresponds to the 9-11 disaster where five switches were out for over a month, while the years 2005 and 2007 correspond to heavy hurricane induced outages. Switches having 7 or less outages are several times larger than switches suffering 8 or more outages. The less frequently failing switches account for 3% of the switches, 25% of the outages, but only 7% of the lost line hours.

b) Rural versus Urban

In both categories, rural switches failed more often than urban switches. However, most of the outages in the category of less frequently failing switches occurred at the start of the study period; whereas, most of the outages in the category of more frequently failing switches occurred towards the end of the study period. Additionally, most of outages in both categories, no matter where the switches are located, resulted from causes other than scheduled maintenance activities. Interestingly, switches failing more often were about three times smaller than switches failing less often. About 52% of less frequently out switches were rural, while about 66% of more frequently failing switches were rural.

c) Outage causes

For all failing switches, random hardware accounts for 33%, Design error 14% and Acts of God/Power outages 20%. The less frequently failing switches suffered considerably more often from scheduled outages; whereas, the more frequently failing switches suffered considerably more often from hardware failures and acts of God (i.e., natural disasters). The more frequently failing switches also often suffered from software design errors, external power failures, massive line outages, loss of facilities between host and remote, and other/unknown causes. There is an impression that the more frequently failing switches suffered from random hardware failures and external circumstances because they were not frequently maintained (i.e., no many scheduled outages); on the other hand, the less frequently failing switches suffered from human procedural errors maybe because they encountered a lot of scheduled outages.

d) Outage duration

The average switch outage duration was 3.3 hours. Even though the average duration per outage in both categories is approximately the same (considering all cause codes), the average impact (LLH) per outage is considerably different. This implies that the more frequently failing switches are smaller than the less frequently failing switches. Perhaps larger switches receive better maintenance responses, but this is not discernible from the data.

e) Time of Day

The differences between the mean times of day in both categories are statistically significant except when

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considering the scheduled outages only.. No additional insights as to why were discernible from the data.

f) Day of Week

The differences between the mean days of week in both categories are also statistically significant. No additional insights as to why were discernible from the data.

g) Month of Year

The differences between the mean months of year in both categories are not statistically significant.

h) Outage/failure trends

For all switches, failure trends exhibited a dramatic increase, when scheduled outages were discounted. The reliability of the less frequently failing switches has been steadily improving during the study period; whereas, the reliability of the more frequently failing switches has been deteriorating during the study period, especially towards the end. No additional insights as to why were discernible from the data.

5) Are there switch models or manufacturers that account for outages/failures more so than others?

In the category of more frequently failing switches, the top three manufacturers of switches that experienced more outages than others are the Northern Telecom, Automatic Electric and Ericsson, although the percentage of those switches in the total switch population is not known. However, Northern Telecom switches accounted for about 38% of the more frequently failing switch outages while Lucent Technologies accounted for only 1.5%.

B. Conclusions and Limitations

This research reveals that there are significant reliability deficits in more frequently failing local telecommunication switches, especially towards the end of the study period (i.e., 2009). In fact, the last three years of the study period show significant reliability deterioration. This research also shows that there are significant differences in the causes of outages, impacts of outages, and switch characteristics between the two categories (the more frequently failing switches and the less frequently failing switches). In fact, only 3% of the failing switches accounts for 20% of all switch outages and for 7% of the lost line hours. Limitations include that the data is non-experimental, reported by a number of different carries who applied many cause codes. The consistency between reporting companies is unknown, as is the accuracy of the reports. Although scheduled outages reduced dramatically, it is not known if those outages induce subsequent failures, such as introducing software/hardware bugs.

The limitations of this work include the fact that outage reports are made by different carriers, and by different people at individual carriers. The danger is lack of consistency in reporting. A counterpoint is that the reporting rules were constant over the study period. The fact the FCC has stopped collecting reports on switch outages since 2009 is unfortunate, as future trends of local telecommunication switch reliability and survivability cannot be assessed from publically available data. However, the trends reveal opportunities for corrective/preventive actions on the part of switch manufacturers and service providers.

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