A PRE AND POST 9-11 ANALYSIS OF SS7 OUTAGES IN THE PUBLIC SWITCHED TELEPHONE NETWORK

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Abstract

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A PRE AND POST 9-11 ANALYSIS OF SS7 OUTAGES IN THE PUBLIC SWITCHED TELEPHONE NETWORK (203 pp.)

Director of Thesis: Andrew P. Snow

The purpose of this thesis is to identify reliability, survivability, and causality differences in Signaling System No. 7 (SS7) outages before and after 9-11. This research addresses questions related to differences in outage frequency, size, duration, blocked calls, impact, time of day, day of week, and causes in pre and post 9-11 outage events. In order to analyze these differences, trend testing, model building, descriptive statistics, mean tests, temporal analysis, and causality analysis were performed. From the analysis it was found that SS7 outage frequency decreased by 60% after 9-11, indicating reliability growth. Survivability is investigated by a variety of impact metrics. A major finding is that the magnitude of impact metrics did not appreciably change. Some significant differences in trigger, direct and root causality were also observed. It was also determined that the direct cause of SS7 network isolation from local and tandem switches was loss of A-links due to human activity, with the root cause being diversity deficits.

Approved:

Andrew P. Snow

Associate Professor of Information and Telecommunication Systems
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Chapter 1

1. INTRODUCTION

1.1 Importance of topic

The terrorist attack of Sept 11 (9-11) had a huge psychological impact on American society. Additionally, the communication networks were severely disrupted and the ability to place or receive telephone calls in New York City was greatly impacted. In fact, a major telecommunications hub was severely damaged in the fall of the World Trade Centers [38], [39], [40] that also affected over 4 million data circuits. Users shifted to email for communication as both telephone and wireless networks were affected by the disaster. Pagers were another means of communication for people [38], [39], [40]. The 9-11 incident is just one example of how society depends on networks. Another is hurricane Katrina, where the dependence on communications during times of disaster was amplified [41]. 9-11 had highlighted the importance of this dependence, and it is reasonable to expect that improvements have occurred since then.

Most voice communication depends on the Public Switched Telephone Network [PSTN], including wireless voice calls. The PSTN is used to transmit voice calls from one subscriber to another using circuit switched technology. Historically the PSTN consisted of telephones, switches, and electrical wires for transmitting voice. Later, the PSTN evolved into three different systems termed switching, transmission and signaling, capable of carrying voice as well as data traffic. The switching system helps in completing end-to-end circuits so that voice signals can be carried from one location to
another. It consists of two types of switches: local switches and tandem switches. Transmission systems provide communication links between switches that are used by the switches to complete end-to-end circuits. A signaling system helps in initializing, terminating and maintaining end-to-end circuits to support calls. Signaling is also required for many important services such as 800 calls and caller ID. Thus, signaling systems play a crucial role in the PSTN network.

The currently used international signaling system standard is Signaling System Number 7 (SS7). Without SS7 capability, calls cannot be processed in the PSTN. Additionally, SS7 is required to place wireless calls. Wireless calls depend on fixed wireline facilities as the “wireless” portion of the call is short.

There has been significant research performed in the past on network outages but little was focused on SS7 outages. Other works have indicated a decrease in telecommunication outages due to power loss after 9-11 [10]. Perhaps, SS7 systems enjoyed the same reliability growth? This work will attempt to address such questions.

1.2 Scope of research

1.2.1 FCC-reportable outages involving SS7 capability

Although the Federal Communications Commission (FCC) requires the reporting of certain large-scale outages, this work considers only SS7 related outages. In this work, any outage that results in the inability of SS7 network to provide voice service will be studied and referred to as an “SS7 Outage”. This study does not include outages that
affect switches or transmission facilities, unless SS7 disruption resulted that affected users. Some outages occurred because of transmission and/or switch failures that impact voice service. In these instances, if SS7 would have otherwise functioned, the outage is not classified as an SS7 outage.

1.2.2 Comparison of SS7 outages before and after 9-11

As will be discussed in the literature review, there was an overall decrease after 9-11 in outage frequency due to all sources (Signaling, Switching and Transmission). This research will compare SS7 outage frequency, impact, and causes before and after 9-11, to see if there were any improvements or deterioration. Sampling will be used in that the work will compare SS7 outages occurring two consecutive years before and two consecutive years after 9-11. All SS7 outages in 1999 and 2000 will be compared to against all SS7 outages in 2003 and 2004. The scope of the study is illustrated in Figure 1.

SS7 Outage Comparison
Frequency, Impact & Cause

Pre 9-11 Sample

9-11 Event

Post 9-11 Sample

1999 2000 2001 2002 2003 2004

Figure 1. Scope of research
1.3 Research goal

The proposed research aims are to identify any reliability, survivability, or causality differences in SS7 outages before and after 9-11. Reliability differences are to be investigated by comparing outage frequency and testing for trends before and after 9-11. Survivability differences will be investigated by comparing SS7 outage impact metrics before and after 9-11, and causality will be analyzed by classifying outage trigger, direct, and root causes, and comparing causality before and after 9-11. Reliability and survivability will then be examined by trigger, direct, and root causality classifications.
Chapter 2

2. LITERATURE REVIEW

The literature review section aims to review relevant research work done in the past to gain knowledge relevant to the field of study, and to establish the relationship of this research to past research. The information gathered while reviewing other authors’ work will act as a basis for further the research. Besides this, the literature review will insure this work adds to knowledge and does not merely repeat the same research. The literature review presented below will focus on outage reporting, an overview of SS7, network dependability, and outage analysis. This information was collected from books, research papers, journals, computer databases, and the World Wide Web.

2.1 Outage reporting in the PSTN

2.1.1 History of outage reporting

The FCC is a US regulatory body formed by the Telecommunication Act of 1934 [18]. In response to many outages in the late 1980’s and early 1990’s, the FCC began to require outage reports from wireline carriers offering voice services [29]. From 1993-2004, the reports were collected and made public. All wireline carriers were required to submit outage reports that exceeded certain thresholds to the FCC. On January 2, 2005, the reporting requirements were extended to wireless, satellite, and cable carriers offering voice service [35]. However, this regulation also dictated that outages would no longer be made public, due to Homeland Security concerns.
The FCC formed a council in 1991 and named it the Network Reliability Council (NRC). One purpose of the NRC was to review the outage reports and provide some guidelines to telecommunication carriers for reducing network failure. Later, this council was renamed by the FCC the Network Reliability & Interoperability Council (NRIC) [15]. NRIC, based on its study of outage reports and with the help of vendors & telecommunication carriers, prepared industry ‘best practices’. Best practices were meant as guidance to telecommunication carriers on the ways of reducing network outages.

NRIC requested assistance in analyzing reports from telecommunication industry [15]. This committee is called the Network Reliability Steering Committee (NRSC). NRSC receives its funds from an association consisting of telecommunication carriers called the Alliance for Telecommunication Industry Solutions (ATIS).

2.1.2 FCC reports

2.1.2.1 FCC reporting threshold

The FCC established reporting thresholds. Most reports are about outages affecting more than 30,000 customers for at least 30 minutes. Reported outages are called “FCC Reportable Outages” [30]. However, there are certain other FCC-Reportable outages called “Special Outages” which do not meet this particular threshold requirement. Examples of special outages include those affecting major airports, 911 service, nuclear power plants, major military installations government facilities, and fire [31]. Both types of FCC-Reportable outages have involved SS7.
2.1.2.2 Contents of FCC reports

An FCC outage report filed by a carrier consists of the name of the carrier, the time at which the outage occurred, date of the outage, outage location, affected geographic area, number of customers affected, number of blocked calls due to the outage, duration of the outage, services affected, background of the outage, and causes (root and direct cause) [1]. Number of customers affected gives information about the total access lines affected due to the outage whereas blocked calls indicate the calls that are unable to be completed due to the outage. However, the number of customers affected does not tell us about the total customers impacted due to the outage. Total customers affected by an outage can be calculated by adding the number of customers affected and one-third of the blocked calls. The rationale for one-third of the blocked calls is that every customer tries at least three times before ending call attempts [10]. Outage reports usually include the reporting carrier’s perspective of direct and root causes of the outage. Direct cause refers to the component failure that resulted in the outage while the root cause provides insight into the outage causality that, ostensibly, will assist in reducing further such outages. For example the direct cause may be failure of SS7 A-links and the root cause can be lack of A-link diversity. However, the quality and consistency of their characterizations from carrier to carrier and event to event is uneven.

2.1.2.3 Analysis of FCC-reportable outages

NRSC classified, analyzed all FCC-Reportable outages (including SS7), and ATIS published yearly PSTN reliability assessments. As this work is sponsored by a carrier association, its objectivity can be questioned, calling for independent assessments.
Additionally, FCC officials often questioned NRSC causality classifications of individual outages.

The paper, *Assessing pain below a regulatory outage reporting threshold* by Snow [30], discussed metrics used for measuring the impact of network outages. This paper investigated a metric called ‘Outage Index’, created by the ANSI accredited Telecommunications Committee T1. The FCC has used another metric called Lost Line Hours (LLH), the product of customers affected and outage duration. Snow, found the weakness in the outage index, because of undue weight to size compared to duration. So he came up with another metric called Prime Line Lost Hours (PLLH). This metric is calculated by multiplying LLH with a Committee T1 time factor, where time factor refers to the level of usage at the time of the outage [30].

Snow in *A Reliability Analysis of Local Telecommunication Switches* [3], Snow, et al. in *Modeling telecommunication outage due to power loss* [5], and Rastogi in *Assessing wireless network dependability using neural networks* [32] also analyzed FCC reportable outages. Snow studied local telecommunication switch failures of 2-minutes or more and performed a reliability analysis. Snow, et al. analyzed FCC-Reportable power outages using trend testing and modeling, while Rastogi, et al. analyzed dependability of wireless network outages using neural networks.
2.2 Overview of SS7

Before discussing SS7 in detail, refer to the PSTN architecture in Figure 2 to understand the importance of signaling in PSTN. The PSTN consists of transmission facilities that connect switches, local loop access lines that act as interface between subscribers and local switches, and signaling facilities that helps in call set up, management, and termination (in addition to supporting intelligent network services) [3].

Figure 2. PSTN architecture [3]
Every call request requires transmission of signaling information before a connection can be established. Similarly, termination of a call also requires exchange of signaling information between the two end points. This signaling is achieved by a system called SS7. Sometimes it is referred to the Common Channel Signaling System 7 (CCS 7) or simply Common Channel Signaling (CCS). As SS7 helps in establishment, maintenance and termination of calls, it plays a crucial role in the PSTN.

2.2.1 History of signaling

Signaling can be of various types such as conventional DC signaling, in-band signaling, out-of-band signaling, digital signaling, and common channel signaling (CCS) [11]. In conventional DC signaling, when a caller picks up the receiver, direct current is sent to the central office. The central office, after receiving this signal, generates a dial tone and sends it back to the caller. The caller can then dial the number and place a call. In-band signaling uses audio voice tones instead of a direct current in the voice circuit. In out-of-band signaling, the signaling information is carried on a frequency different from the frequency band used for voice transmission. However, the two share the same voice circuit. Digital signaling uses signaling bits to exchange signaling information as opposed to CCS which exchanges messages. CCS is the most commonly used signaling these days. It separates the signaling from the voice circuit by using a different network for the exchange of signaling traffic. Signaling System 6 (SS6) was the first generation CCS standard, created in the late 1960s. It was followed by another standard called SS7 in the 1970’s which is used today [13]. There is almost 100% penetration of SS7 in US [42]. In addition, SS7 is a key element for migration of carrier to VOIP [36].
2.2.2 SS7 architecture and its components

Since signaling messages are short and require rapid transmission, SS7 is based on packet switched technology as opposed to circuit switched technology used in PSTN. SS7 network consists of various nodes called “signaling points” (SP). An address is associated with each signaling point. This address is called “point code”. SS7 architecture with various SPs is shown in Figure 3. The circuits interconnecting these nodes are supposed to be totally separate from trunk groups used by switches (SSPs) to setup voice circuits [13].

In the SS7 network, signaling information is transmitted as messages. Each message contains the point code of the source as well as destination [13]. Moreover, every SP is capable of reading the messages and determining whether the message is destined for it. It also has a routing table for establishing routes to other SP’s. Various types of SPs are [11] –

1. Service switching point (SSP)
2. Signal transfer point (STP)
3. Service control point (SCP)
2.2.2.1 Service switching point (SSP)

An SSP is a local or tandem switch which originates, terminates, and switches calls. It is connected with other signaling points through signaling links.

2.2.2.2 Signal transfer point (STP)

An STP acts as a packet switched router for the SS7 network. It routes the signaling messages from one SSP to another or from SSP to SCP, via signaling links. STPs are usually implemented in geographically diverse pairs to provide redundant access to SSPs. STP is categorized into three categories. They are:

1) National STP
(2) International STP

(3) Gateway STP

(1) National STP –

The STP that functions within national boundaries is called a national STP. It is used to interconnect the SS7 networks with the same message format.

(2) International STP –

The STP that works outside national boundaries is an international STP. It is used to interconnect networks of different countries using the same International Telecommunication Union (ITU) standards.

(3) Gateway STP –

A gateway STP is used for connecting the networks with a different carrier or to interconnect different countries following different national standards. It has the ability to perform protocol conversions from different national standards to ITU standard. It also provides network security [12].

2.2.2.3 Service control point (SCP)

An SCP provides access to the database containing routing information related to 800 calls, caller identification and calling card verification information, billing information and information related to other advanced intelligent services [11]. Usually SCP’s are implemented in pairs to provide redundancy in case of failures.
2.2.3 Typical call set up in SS7 networks

To help set up a typical voice call, a call request is sent to an SSP. The SSP converts the dialed number into a signaling message and sends over the SS7 network. The SSP looks for the dialed number in its routing table to find the route and the destination. The SSP communicates with the adjacent STP to route the message through the SS7 network to its destination. This way the signaling call finally reaches the destination SSP via STPs.

2.2.4 Database query call

A voice call request to an unknown SSP, like an 800 number, requires database lookup which resides at an SCP. The SSP sends the request to an STP which in turn communicates with the SCP to access the database. The SCP sends the number translation information back to the SSP via STPs so that a voice call can be established.

2.2.5 Signaling data links

The various SS7 components are connected through different types of communication links, listed below and shown in Figure 4 & 5.

1. Access links (A-links)
2. Bridge links (B-links)
3. Cross links (C-links)
4. Diagonal links (D-links)
5. Extended links (E-links)
6. Fully associated links (F-links)
These different links are described below [11]:

(1) A-links:

The link between an SSP and STP or between STP and SCP is refereed as an ‘A-link’, as shown in Figure 4. Absence of physical or logical diversity in A-links can result in isolation of switching system from the signaling system.

(2) B-links:

The links bridging one pair of STPs to another pair of STPs at the same hierarchal level is a ‘B-link’.
(3) C-links:
The link between mated STPs is a ‘C-link’ as shown in Figure 4. C-links are used to carry management messages. However, in the case of congestion C-links carry routine messages that are normally carried by A-links and B-links.

(4) D-links:
‘D-links’ serve the same function as B-links, except that they are used to connect STP pairs at a different hierarchal level.

Figure 5. D-links & E-links [11]
(5) E-links:

The link that connects SSP to a remote STP is called an ‘E-link’. It is again used to provide diversity in the SS7 network in case of failure.

(6) F-links:

The link between two SSPs is an ‘F-link’. It is either used for load sharing during congestion or when the STP becomes unreachable. In some of the outage reports it was found that outages occurred due to lack of diversity in C-links and D-links. However, most outages were due to lack of diversity in A-links.

2.2.6 Importance of SS7 networks

SS7 is based on CCS principles and uses a separate network for transferring signaling information. Thus, it has increased capacity for voice circuit because the trunks are not involved in signaling. This means that voice circuits are occupied only for the duration of user calls and become available immediately after the conversation is over. Some of the features of SS7 include number portability support, caller identification, data security, routing of 800 numbers, calling card authentication verification, automatic callback, and use of other advanced intelligent services [11].

2.3 Network dependability: reliability and survivability

Dependability is comprised of reliability, survivability, availability, maintainability, confidentiality, integrity, and safety [37]. This research concentrates on reliability and survivability aspects of dependability. Availability and maintainability are out of scope of
Reliability is defined as the “probability that a network service is satisfactorily operational over a specified period of time” [4]. Snow, et al. in *Modeling telecommunication outages due to power loss* did reliability analysis of power, studying telecommunication power outages for an 8 year period i.e. 1996-2003. The authors found that network reliability improved after 9-11. They established a model called a ‘jump point model’ indicating that the frequency of power outages dropped suddenly after Sept 11 [5].

In *A Reliability Analysis of Local Telecommunication Switches*, Snow performed reliability analysis on local telecommunication switches over the period from January 1991 through December 1995 [3]. He discovered reliability growth in local telecommunication switches. Snow & Weiss in *Empirical Evidence of Reliability Growth in Large-Scale Networks* emphasized the importance of analyzing reliability and NHPP (non-homogeneous Poisson process) processes in large scale networks. They studied FTS2000 network outages and concluded that continuous power law reliability improvement occurred, NNHP models help prediction of future outages, and pointed out the importance of changing trends [6].

Survivability is the probability that a network will be substantially operational during a significant fault condition. Survivability metrics include outage impact. Various parameters used to measure impact include outage duration, customers affected, blocked calls and service importance. Network design plays a crucial role in improving survivability. However, a fault tolerant network design is not sufficient to enhance
survivability if it is not properly implemented and operated. Snow & Thayer, in their paper *Defeating Telecommunication System Fault-Tolerant Designs* discussed how fault-tolerant designs in signaling, transmission, and power can be defeated by improper deployment [7]. The authors mentioned lack of redundancy and over-concentration as the reason such designs were defeated. This was illustrated by an outage example where both A-links received power from the same power source, which failed. The failure to follow best practices as a reason for outages was also pointed out. The authors were consistent in their assertion that many network outages occur due to fiber cuts. However, the root cause of these outages is not ‘fiber cut’ as claimed by carrier industries and ATIS, but unprotected transmission facilities [7]. In *Network Reliability: The Concurrent Challenges of Innovation, Competition and Complexity* Snow also questioned reliability of fault tolerant design deployment. According to him competition can be a vital factor in improving the reliability of such networks. He also gave an example where an SS7 network outage occurred due to failure to follow best practices. The reason for the outage was improper deployment of A-links which shared the same fiber, same cable or same conduit. He also pointed out that a statistical perspective tracks trends, while an engineering perspective is to change trends [8].

**2.4 Outage analysis**

**2.4.1 ATIS annual reporting**

The ATIS annual report 2004 [9] consists of an analysis of the wireline telecommunication network outage reports submitted to the FCC. It compared the outages in 2004 to all the previous years (i.e. starting in 1993). In this report, network
performance by outage frequency, duration, and customer potentially affected, and outage index data matrices were inspected. The report declared a decreasing trend in outage frequency over the period 1993-2004. Some of the findings related to SS7 outages in the ATIS Annual Report 2004 were that there is no significant trend in SS7 outages from 1993 through 2004. Also, there was no trend found in SS7 survivability. However, the presence of seasonality was asserted. It was also stated that duration of SS7 outages and customers affected due to SS7 outages is less as compared to other failure categories. The major cause of SS7 outage is asserted to be isolation of switches from the SS7 network. According to the report, nearly 71% of SS7 outages result from SS7 isolation, 11% due to link set(s), 8% due to STP failure, and 5% due to SCP failure [9]. Root cause methodology was not discussed and trigger causes were not covered.

2.4.2 Reliability perspective: outage frequency

Frequency of outages (reliability) is an important metric in analyzing presence or absence of trends. Decreasing frequency over time is reliability growth, while increasing frequency over time is reliability deterioration [19]. Outage arrival time, or the time of the failure event started, is analyzed as frequency. Snow, et al has used frequency to examine telecommunication outages due to power loss in *Modeling telecommunication outages due to power loss* [5]. They formulated an NHPP Poisson model for demonstrating the significance of the difference in frequency of these type outages before and after 9-11. They found that frequency of power outages had reduced significantly after the 9-11 event. A paper presented by Snow in an international conference also used frequency as a means of analyzing local switch outages which lasted 2-minutes or more.
He observed the local telecommunication switch outages from 1991 through 1995 and discovered the reduction in local switch outage frequency [3].

2.4.3 Outage causality & categorization

Enriquez, et al categorized outages as human-company, human external, software, hardware, acts of nature, vandalism, and overload [1]. Human company refers to the outages that are triggered by humans that are part of a telephone company. They can be technicians working in the company or vendors or contractors who are working for the company. A human external involves people who are not associated with company but whom accidentally come in contact with company’s network and cause an outage. Hardware is comprised of those outages which are caused due to hardware malfunction or failure of equipment associated with the concerned network. Failures that occur due to software bugs fall under the category of software outages. Acts of nature involve outages due to natural disasters which are out of reach of humans. It can be an earthquake, a storm, or a flood. Vandalism includes outages because of willful damage to the network. Overload is a condition where a network is incapable of handling the call volume and causes an outage. The authors did not distinguish between the ‘acts of nature’ and ‘human company’. For instance, if a flood caused batteries placed in the basement to short, would Enriquez, et al. classify as an ‘act of nature’ or ‘human company’ for placing batteries below ground level?

Snow, et al in *Power related network outages: impact, triggering events, and root causes* studied power outages and determined three causes for each outage - trigger, direct and
root cause [2]. By trigger, they mean the initial event in the sequence of events which lead to an outage. The direct cause is the last event that took place before the outage and the root cause is the basic cause of an outage which, if eliminated or corrected, will reduce the probability of such outages in the future. They further subdivided trigger causes as natural disasters, power surges, communication equipment AC loss and human errors [2]. They also classified root causes as engineering error, installation error, operations error, maintenance error and unforeseen/unknown [2]. The nature of SS7 outages versus power outages is not amenable to classifying SS7 outages with the same casual definitions.

In *A Reliability Analysis of Local Telecommunication Switches* paper Snow categorized switch outages based on the cause codes as human error, design error, hardware error, external circumstances, and other/unknown [3]. Human errors includes errors made by the humans (technicians, vendors or contractors) while performing maintenance, installation, operations and other engineering activities [3]. Design error refers to the error associated with network, hardware, or software design. Hardware error is due to random malfunctions or failures of hardware or links, the same as one used by Enriquez, et al. The unknown category comprised of outages whose cause is not known.

2.4.4 Survivability perspective: assessing the impact of outages

Snow, et al in their paper on *Power related network outages: impact, triggering events, and root causes* measured the impact of power outage by a metric called “lost customer hours” [2]. This metric proves helpful in comparing the outage causes. A lost customer
hour is calculated by multiplying the duration of the outage in hours with total number of customers affected. In order to stratify the outage impact and look for causality differences, the authors came up with three categories: low, medium and high impact due to the outage. A lost customer hour value of less than 250,000 is categorized as low impact, greater than or equal to 250,000 & less than 1000,000 is categorized as medium impact and value greater than or equal to 1000,000 is categorized as high impact. It was found that 60% of power outages are low impact while 40 % are either medium or high impact, 20% each. Also, on comparing trigger causes, it was discovered that most outages (38 %) are triggered by AC power loss and 30 % are triggered by carrier human errors. Analysis of root cause revealed that 33 % of total outages are due to carrier operations error. It further indicated that many power outages can be easily avoided [2]. A number of aspects of this paper will be useful in our methodology such as the use of metric called “lost customer hours” for measuring impact, and the categories used for assessing the causality impact

Enriquez, et al used another metric called “customer minutes” for measuring the impact of outages. Customer minutes are calculated by multiplying the duration of outage in minutes with the number of customers affected [1]. This metric is the same as LLH, the only difference is that LLH is in hours and customer minutes are in minutes. Using customer minutes, it was found that human errors caused 63 % of the total outages. Enriquez also used blocked calls for comparing the outage causes and found that humans caused most of the blocked calls amongst all categories [1].
Chapter 3

3. RESEARCH QUESTIONS

Research questions are the specific questions to address in order to meet our research goal. The following questions consist of the reliability, survivability, and causality questions necessary to address the research goal.

3.1 Research Question 1 on reliability: outage frequency

1. Are there any differences in SS7 reliability (the failure frequency) before & after 9-11?

Through this question we will try to find whether there is also reliability growth in overall outages and SS7 outages. This question intends to detect any difference in the SS7 outages before and after 9-11, by comparing their failure intensity and trends.

3.2 Research Question(s) 2 on survivability:

3.2.1 Research Question 2(a) on outage size

2 (a) Is there any difference in the size of SS7 outages before and after 911, in terms of isolated access lines?

To address this question, we investigate the size of outages by comparing isolated local switch access lines before and after 9-11.
3.2.2 Research Question 2(b) on outage blocked calls

2 (b) Is there any difference in the number of blocked calls before and after 9-11?

This information, along with number of customers affected will help us to calculate the total number of customers affected due to the outage. Therefore, comparing the blocked calls after and before 9-11 will provide useful information about the impact of SS7 outages. The answer to this question helps us know whether there were any improvements in the network characteristics to decrease blocked calls after 9-11.

3.2.3 Research Question 2(c) on outage duration

2 (c) Is there any difference in the duration of SS7 outages before and after 9-11?

Duration of the outage is an important parameter in determining survivability of the network. Increase in outage duration after 9-11 would indicate a decrease in survivability and vice versa. Thus, the results obtained from the above question will demonstrate whether the survivability of the network is improved or weakened after 9-11.

3.2.4 Research Question 2(d) on outage impact

2(d) Is there any difference in the impact of SS7 outages before and after 911 in terms of total customers affected?

This question investigates the impact of SS7 outages by comparing the total number of customers affected before and after 9-11. The impact before and after will also be
stratified and compared. Moreover, the answer to this question will uncover various facts about technology and/or process change, and whether that change has improved or deteriorated SS7. It will also determine whether the carrier industry is following best practices, how effective the best practices are, and whether industries have learned from past experience or repeating the same mistakes.

3.2.5 Research Question 2(e) on outage time of day

2 (d) Is there any differences in time of day at which SS7 outages occurs before & after 9-11?

This question will investigate any correlation between time of the day and the outage events. For time of the day comparison, a 24-hour day is divided into six time slots of four hours each. This will allow time of day comparisons before and after 9-11.

3.2.6 Research Question 2(f) on outage day of week

2 (e) Is there any temporal difference in SS7 outage occurrence by day of the week before & after 9-11?

This question will help us to determine any relationships between day of the week and the outage events before and after 9-11. Investigations will be carried out for weekdays and weekends, in order to identify any specific days of the week, and whether this scenario remains the same before and after 9-11. Thus, this information will provide insights into temporal occurrence.
3.3 Research Question 3 on causality:

3. Is there any difference in the causes of SS7 outages before and after 9-11?

Knowing the cause of an outage is a critical factor in future network improvements. This question will be addressed for the trigger, direct, and root causes. Answer to this question will help understand the mechanisms of SS7 vulnerability, and help to decrease outages.

3.4 Research Question 4 on causality and survivability relationships:

4. Are the relationships between causality and survivability the same before and after 911?

This question aims to address the relationships between causality and survivability metrics after 9-11. Various survivability measures such as isolated access lines, blocked calls, outage duration, total customers affected, time of day, day of week, and impact have differences in causality. This question will provide insights into casual-survivability relationships before and after 9-11.
Chapter 4

4. METHODOLOGY

4.1 Outage sampling

A convenience sampling technique was used to sample the SS7 outage data before and after 9-11. Convenience sampling is a technique where the sample is selected based on data availability or convenience [26]. Thus, it was decided to consider all SS7 outage reports in 1999-2000 against all in 2003-2004. One factor in this selection was that the FCC reports after the 2004 are not accessible to public. However, the primary reason was to temporally balance the samples and avoid potential years where process change might occur abruptly, we selected 1999-2000 and 2003-2004 for comparison. So pre and post SS7 outage data sets were created for separate analysis. Analyzing and comparing these two data sets will give useful insights into the effect the 9-11 event might have had on telecommunication industry and society.

4.2 SS7 outage incident selection

After sampling the data, all the FCC-Reportable outage reports involving SS7 outages were selected. The selection criterion for an “SS7 outage” was any report in which loss of SS7 capability resulted in inability of users to communicate. After reviewing all the FCC reports for 1999-2000 and 2003-2004, 145 out of 689 reports involved SS7 outages. The numeric results of the selection are shown in Table 1, while a bar chart comparison is shown in Figure 6. Also, the trend in SS7 outages is shown in Figure 7.
Table 1. Total outages and SS7 outages before and after 9-11

<table>
<thead>
<tr>
<th>Year</th>
<th>Total FCC Reportable Outages</th>
<th>SS7 Outage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>230</td>
<td>42</td>
</tr>
<tr>
<td>2000</td>
<td>224</td>
<td>48</td>
</tr>
<tr>
<td>2003</td>
<td>126</td>
<td>32</td>
</tr>
<tr>
<td>2004</td>
<td>109</td>
<td>23</td>
</tr>
</tbody>
</table>

Figure 6. Total outages vs. SS7 outages
These graphs and table seem to indicate that both the total number of outages and outages due to SS7 have reduced significantly after 9-11. Hence, it increases a possibility of relationship between the 9-11 event and outages.

A graphical representation of percentage of SS7 outages out of total outages is shown in Figure 8. A visual examination of the graph seems to indicate little difference in % of SS7 outages before and after 9-11. In order to further investigate these results, we performed an ANOVA test for the data shown in Figure 8. The results of ANOVA are also discussed.
Figure 8. SS7 outages as a percentage of total outages

In order to understand the significance of the results shown in Figure 8, we performed ANOVA test. The null hypothesis for this test was “there is no difference in the % of SS7 outages before and after 9-11” whereas alternate hypothesis was that “there is a difference in % of SS7 outages before and after 9-11.

The P-value obtained from ANOVA is 0.35. This high p-value indicates that we cannot reject the Null Hypothesis that there is no difference in % in the frequency of SS7 outages before and after 9-11.

4.3 Data compilation

The data for each data set were compiled in Excel. The data comprised of the following variables: Outage date, Outage time in EST, Number of customers affected, Blocked
calls, Duration in minutes, and Total number customers affected. Data associated with all these variables were collected directly from each outage report except the data for Total number customers affected, which was calculated by following formula [10]:

\[
\text{Total number customers affected} = \text{No. of customers affected} + \frac{1}{3} \times (\text{No. Blocked calls})
\]

Thereon quantitative analysis was performed on the data. The background of each outage and the carrier’s causality description were also collected as text for later qualitative analysis.

**4.4 Quantitative analysis**

**4.4.1 Visual examination**

Visual plots are pictorial representation of data indicating the relationship between two variables [26]. Cumulative plots are one such visual plot which helps us to investigate reliability trends. If a cumulative outage plot bends downward, it indicates reliability growth while if it bends upward it implies reliability deterioration [3]. *Modeling telecommunication outages due to power loss* by Snow, et al. examined cumulative plots to visually assess reliability trends of power outages. *Empirical Evidence of Reliability Growth in Large-Scale Networks* by Snow & Weiss also considered cumulative plots for large scale network outages and identified the criterion for applying NHPP. Snow in another paper on *A Reliability Analysis of Local Telecommunication Switches* has also used cumulative plots to understand the reliability trends and to help distinguish Non-homogeneous Poisson process (NHPP) from Homogeneous Poisson processes (HPP).
An HPP is a process where the failure rate does not vary with time i.e. the failure rate is constant, whereas an NHPP is a process in which the failure rate varies with the time or is not constant. [19]. Further, if the cumulative plot of failures vs. time is linear then it is suggestive of an HPP. However, if there is either reliability growth or deterioration then it’s suggestive of NHPP [3]. A cumulative plot of SS7 outages for the time period 1999-2000 is displayed in Figure 9.

The plot in Figure 9, suggests that initially there was reliability growth but slowly towards the end of 1999 there was reliability deterioration. This was followed by a suggestion of reliability constancy, growth and deterioration in 2000. Now, let’s take a
look at cumulative plot for 2003-2004. A cumulative plot of SS7 outages during 2003-2004 is shown in Figure 10.

![Cumulative SS7 outages vs. time from 2003-2004](image)

**Figure 10. Cumulative SS7 outages vs. time from 2003-2004**

The scatter plot in Figure 10 is a plot between the cumulative number of outage events from 2003-2004 and the time each outage occurred. The plot seems to bend downward indicating reliability growth from 2003 through 2004. To further investigate these cumulative plots, formal trend testing was necessary.

### 4.4.2 Trend testing

Trend testing is used for testing a Null Hypothesis of no trend. The Laplace trend test produces a test statistic to assess the strength of trend inferences, and is given by [10]:

\[ T = \frac{\sum_{i=1}^{n} (x_i - \bar{x}) (y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}} \]
\[ U = \sum T_i - \left(0.5 \times N \times T_0\right) \]
\[ \frac{1}{T_0 \times \sqrt{N/12}} \]

Where \( U \) converges to normal Z-score for \( N \) greater than 3. In the above formula, \( T_i \) is the time of \( i^{th} \) failure, \( N \) is the total number of failures, and \( T_0 \) is the total time observing outage events in the network [20].

If the value of \( U \) is too high then we will reject the Null Hypothesis that there is no trend and accept the Alternate Hypothesis that there is a trend. Likewise, if the value of \( U \) is too low we will accept the Null Hypothesis. In addition, a positive \( U \) value indicates possibility that there is a reliability growth whereas a negative \( U \) value implies reliability deterioration. The \( U \) score is used to determine a statistical inference of trend or no trend from normal distribution 1-tail test [20].

4.4.3 Poisson modeling

A model is used to explain the relationship between variables. Poisson regression can be used to model relationships between failure counts and explanatory variables. Linear regression should not be used where variables are not continuous [25]. The general equation of a Poisson model is given by [25]:

\[ \log \mu_i = b_0 + b_1 \cdot x_i \]
Where $\mu_i$ is the mean intensity, $x_i$ corresponds to the explanatory variable and $b_0$ and $b_1$ are the constants values associated with explanatory variables [10].

The Poisson model was used in *Modeling telecommunication outages due to power loss* and it was found that for the years before and after 9-11 the failure rate was constant. However, it was also found that the intensity of power outages reduces after 9-11. The model was called a jump point model as the frequency suddenly fell after 9-11.

To build a model, Poisson regression was executed using, monthly outage count data and explanatory variables. The explanatory variables investigated were an indicator variable representing pre and post 9-11 and time. The first model involved all FCC-reportable outages from 1993-2004. Two other Poisson models were built, one involving SS7 outages during 1999-2000 and the other during 2003-2004. The explanatory variable in these two models was time. The Mac ANOVA (Macintosh Analysis of Variance) software tool, developed by University of Minnesota, was used to perform Poisson regression.

### 4.4.4 Descriptive statistics

Descriptive Statistics provides a description of data in the form of summary statistics such as mean, mode, and median, among others [26]. It is a very simple way of representing the data so that it can be compared with other variables used in the research. In this study, we compared the descriptive statistics for each variable before & after 9-11. The variables used for comparison are access lines (number of customer affected),
blocked calls, duration, and total customers affected. The parameters of descriptive
statistics that were considered are the maximum value, the mean, and the median.
Maximum value indicates the highest value in the data range and the mean is the average
of the entire data. Median is the indicator of central tendency. Descriptive Statistics was
performed using Statistical Package for the Social Sciences (SPSS).

4.4.5 Comparison of means
The test employed to compare means was the \( t \)-test. The \( t \)-test is used for Hypothesis
testing where the Null Hypothesis states that there is no difference in sample means.
Thus, if the \( t \)-test statistic is very high, the Null Hypothesis will be rejected and it would
be concluded that there is no difference in the two means, or that the difference between
the two means is not statistically significant.

Usually a \( t \)-test value more than +2.00 or less than -2.00 are considered to be high enough
to reject the Null hypothesis [26]. The tool used in this research to calculate \( t \)-test was
Microsoft Excel.

\( T \)-test statistics were calculated to compare means of each metric, before & after 9-11.
Various metrics considered were the number of customers affected, blocked calls,
duration, and total number of customers affected.
4.5 Qualitative analysis

In the above sections we have concentrated on the quantitative analysis of outages. From hereon we will be focusing on the qualitative aspects of SS7 outages. By qualitative analysis, we mean analysis of non-numeric data [26]. In this research qualitative analysis was performed to identify the sequence of events leading up to the outage, the trigger, direct and root causes, and casual category. Casual categories were created for the three causal types (trigger, direct, and root) and each outage was classified with these causal descriptors.

4.5.1 Analysis of causality

Snow et, al. in *Power related network outages: impact, triggering events, and root causes* had analyzed the causality of power outages by dividing them into three categories: trigger, direct, and root. Thus, it was thought to use the same major casual types to analyze SS7 outages in our research also. Each outage therefore has three causes.

In this research, the SS7 outages, the trigger cause is defined as an event that initiated the loss of an SS7 component. The direct cause is the SS7 failed/congested component that resulted in loss of SS7 capability. Root cause is “The most basic reason, which if eliminated, would prevent recurrence” [33]

Analysis of outages based on their root cause is referred to as “Root Cause Analysis” (RCA) [2]. RCA technique is illustrated below with some examples in section 4.5.3.
4.5.2 Categorization

SS7 outage causes are grouped into trigger, direct, and root causes. These outage causes are further discussed in the following sections.

4.5.2.1 Trigger cause categories/subcategories

Trigger causes have been divided into following categories/subcategories:

- Fiber Cut
- Human Activity
- Equipment failure
  - Hardware
  - Software
- Power Source
- SS7 Network Overload
- Environmental Factors
- Unknown

Definitions for trigger causes follow:

- **Fiber Cut**: Fiber cut involves all those SS7 outages triggered outside a communication facility due to a severed or damaged fiber. For example, if a construction crew severed fiber cables which contained A-links, then the trigger cause would be fiber cut.

- **Human Activity**: Human Activity comprised of all those outages where carrier or contractor personnel working within the facility accidentally triggered an SS7 outage. For example, if a technician drops a screw driver on a power breaker,
resulting in power loss to A-links, then the trigger cause of this outage will be categorized as human activity.

- **Equipment failure**: The equipment failure category consists of SS7 outages where either equipment hardware or associated software failure triggered an outage. For example, if the timing card fails that provides timing information for the A-links, causing loss of synchronization, then the trigger cause of outage will be categorized as Equipment failure (hardware). An example of software failure can be the failure of software in an SCP which impaired SS7 signaling capability.

- **Power source**: Power source comprised of those SS7 outages in which a power anomaly/failure, not caused by carrier personnel or contractors, caused SS7 component failure. For example, if the SS7 outage occurs due to loss of power to an STP, then it would be categorized under power source trigger category.

- **SS7 network overload**: Sometimes congestion in SS7 components causes impaired or lost SS7 signaling capability. The trigger cause of these outages is referred to as SS7 network overload. For instance if the SS7 traffic in an SCP increases beyond capacity causing SCP impairment and finally SS7 outage due to SCP’s inability to process 800 calls, then the trigger cause of this outage would be categorized as overload.

- **Environmental factors**: If an outage is triggered by an earthquake, storm, vegetation, water ingress or HVAC failure, then they are categorized under environmental factors.

- **Unknown**: If the trigger cause cannot be determined from the report, it is categorized as unknown.
4.5.2.2 Direct cause categories/subcategories

Direct cause categories/subcategories include:

- SCP failure
- STP failure
- SS7 Network Failure
- Switch SS7 process failure
- A-links failure
  - Direct Links
  - DACS
  - SONET ring
  - MUX
  - Transmission Clock
  - Switch A-link Interface
- Unknown

The major equipments/software associated with direct causes is shown in Figure 11.
Figure 11. Direct causes
Definitions for these direct causes follow:

- **SCP Failure**: Failure/Malfunction of either SCP or the software associated with it is categorized under SCP failure.
- **STP Failure**: Failure/Malfunction of STPs is categorized under STP failure.
- **SS7 Network Failure**: SS7 network failure consists of failure of C-links, D-links or any other link associated with SS7 network, other than A-links.
- **Switch SS7 process Failure**: Failure of the software or the processor inside the switch that provides switch SS7 capability is termed as Switch SS7 process failure. In addition, any failure associated with routing translations in a switch is also included in this category. For example, the deletion of routing entries from the switch or addition of wrong entries is classified as a switch SS7 process failure.
- **A-Link Failures**:
  - **Direct Link Failure**: Failure of end to end A-link is categorized under direct link failure.
  - **DACS Failure**: DACS is a digital access and cross-connect switch. Failure of DACS which causes A-link failure is categorized under DACS failure. DACS failure is shown in Figure 12.
  - **SONET ring Failure**: Failure of SONET ring associated with A-links is categorized under SONET ring failure.
  - **MUX Failure**: SS7 outage due to failure of multiplexers which further causes loss of A-links is categorized under MUX failure.
- **Transmission Clock Failure**: Transmission clock provides clocking information for the A-links. Failure of this clock is categorized under transmission clock failure.

- **Switch A-link interface Failure**: By switch A-link interface we mean an interface which connects A-links to the switch. It is also sometimes called ‘Common Network Interface (CNI)’. Failure of CNI interface is categorized under Switch A-link interface failure.

- **Unknown**: This category involves all those outages where the report doesn’t provide enough information that can be used to categorize them under any of the direct causes.
4.5.2.3 Root cause categories/subcategories

Root cause categories/subcategories include:

- Procedural Error
- Maintenance Error
- Design Errors
  - Software
  - Hardware
• Diversity Deficit
  o A-links
  o C-links
  o D-links
  o Power feed
  o Equipment Single Point of Failure (Equip SPF)

• Unknown

Root cause definitions follow:

• **Procedural Error**: A procedure is a “series of actions conducted in a certain manner” [43]. Thus, a procedural error is a failure to follow an established procedure. This category involves outages where the carrier technician/vendor/worker/contractor did not follow the correct process to accomplish a task. An example of this error might be a technician installing power leads to an SS7 component in reverse order, causing the circuit to open resulting in an outage.

• **Maintenance Error**: Maintenance is “The work of keeping something in proper condition” [34]. Maintenance here means keeping the equipment and the facility in proper condition in order to reduce any chances of outage. The outages that results from not maintaining either the equipment or the facility is categorized as maintenance error. For example, after heavy rain the roof started leaking causing SS7 electronic equipment to fail. Thus the root cause of this outage is improper maintenance of the facility. Hence it would be categorized as maintenance error.
• **Design Errors**: Hardware design error involves improper use of flawed hardware equipment or improper deployment of equipment, whereas software design error involves software bugs, faults or bad firmware.

  o **Hardware Design Error**: An example of hardware design error is where the power plant was placed in the basement which is subject to flooding. So, when a water main broke it flooded the basement causing failure of the power supply resulting in an outage because other CO A-links used transmission systems that went through this facility. The root cause of this outage is the design error of placing the power plant in the basement.

  o **Software Design Error**: An example of software design error is where the error in the software caused calls to get misrouted which resulted in dropping of calls and call blocking. Such an outage will be categorized as a software design error.

• **Diversity Deficit**: Diversity deficit implies the absence or lack of diversity in equipment, power, or links. The outages that occurred because of absence of diversity are categorized as a diversity deficit. Though diversity deficit might be a design error, it was found in the majority of outages, so we categorized them separately. Moreover, this categorization has made it easy for us to analyze those outages by further subdividing them. Diversity deficit is further divided into subcategories based on the component which lacked diversity.

  o **Link diversity deficit** – This is where the SS7 outage occurred due to loss of both point-to-point A-links. For example, if the redundant A-links are carried on a single fiber sheath which is severed, then it implies diversity
deficit of A-links. Similarly, lack of point-to-point C-link and D-links are subcategorized as a link diversity deficits. SS7 link diversity is also mentioned in one of the best practices [44].

- **Power Diversity Deficit** – This is where an outage occurred because there was no power diversity to SS7 equipment. For example, A-links receive timing from timing source equipment. If the timing source equipment receives power from a single source, then the failure of power to the timing source equipment can cause an SS7 outage. This outage will be subcategorized as a power diversity deficit. Power diversity is also mentioned in one of the best practices [44].

- **Diversity Deficit: Equip SPF** – This subcategory involves outages where there was an equipment single point of failure. For example, if a single DACS (equipment used for cross connecting A-links) carrying A-links, fails, as shown in Figure 12. Then the root cause of the outage will be the lack of diverse equipments to carry A-links. Hence, it would be categorized as an equipment SPF diversity deficit. Single point of failure is also mentioned in one of the best practices [44].

- **Unknown**: This category involves all those outages where the report does not provide enough information to categorize the root cause.
4.5.3 Examples of RCA

Below are the examples of RCA technique, each providing application of trigger, direct, and root cause.

Example 1 (Report 03-68)

A tree fell on an aerial fiber cable which severed the fibers. This resulted in an SS7 outage as both the A-links were in the severed fiber sheath.

Trigger Cause: Fiber Cut

Direct Cause: A links failure (direct links)

Root Cause: A-link diversity deficit.

Example 2 (Report 00-92)

A vendor while working on timing leads accidentally blew the fuse for the power feed that supplied power to the facility clock distribution unit. The A-link transceivers derive timing information from that clock. Thus, as the clock failed, the A-links also failed, causing an SS7 Outage.

Trigger Cause: Human Activity causing DC power fuse to blow

Direct Cause: A-links failure (transmission clock)

Root Cause: Diversity Deficit (power feed).
Example 3 (Report 00-101)

Digital clock distributor (DCD) is unable to switch the timing card to protection after primary card failure. Both A-links received timing from the same timing card, which failed. This caused local switch isolation from SS7 network.

**Trigger Cause:** Hardware equipment failure (EF-HW)

**Direct Cause:** A-links lost (AL-CLK)

**Root Cause:** The root cause of this outage is equipment diversity deficit (DD-SPF) because both the A-links were timed from the same card in DCD.

Example 4 (Report 99-115)

A defective hardware in CNI ring node was left un-repaired for an unknown time. During routine maintenance activity the CNI ring tried to use the defective hardware and the ring lost the capability to send/receive messages. Also, the switch software did not detect the CNI fault. As a result the Lucent 5ESS switch was isolated from its A-links and the SS7 network.

**Trigger Cause:** Preventive maintenance activity (HUM)

**Direct Cause:** A-links lost (AL-IF)

**Root Cause:** Faulty SS7 switch process bug (DSN-SW)
**Example 5 (Report 99-99)**

A technician working on a switch alarm problem accidentally removed translations for routing digital circuits. This disconnected a central office from SS7 access as it misrouted A-links, causing an SS7 outage.

**Trigger Cause:** Human Activity causing deletion of routing information

**Direct Cause:** Switch SS7 process failure

**Root Cause:** Procedural error

After these categorizations, the causal data can be analyzed in a number of ways, looking for category differences in pre and post 9-11 SS7 outages.

4.5.4 Analysis of outages with the same causes

The causes were put in a database in order to find the frequency of outages with the same trigger, direct and root causes in pre 9-11, post 9-11, and total sample. Results of these queries will help us to identify prevalent combination of trigger, direct and root causes. These results will also be helpful in determining the difference in causality pre and after 9-11. These queries were performed using Microsoft Access.
Chapter 5

5. ANALYSIS AND FINDINGS

5.1 Reliability Poisson model for all FCC-reportable outages 1993-2004

The reliability analysis of SS7 outages is presented as Laplace trend test and Poisson model results.

In Section 4.4.3, the Poisson Regression methodology was explained. In this section a Poisson regression results are shown for all the FCC reportable outages occurring from 1993 through 2004. The results are shown in Figure 13. The model shown in Figure 19 is called a jump point model as there is sudden drop in the frequency of outages after 9-11.
The Poisson model in Figure 13 is

$$\log \mu_t = 5.143 - 0.5546 \cdot i$$

where ‘$i$’ is the indicator variable (0 for pre 9-11 and 1 for post 9-11). This results in:

$$\mu_t = 171 \quad t \leq 2001$$

$$\mu_t = 98 \quad t > 2001$$

The p-values for the model and the regression coefficients were smaller than 0.000000. These p-values indicate that the model is highly significant, strongly implying that the
frequency of all outages reduced significantly after 9-11. This further indicates reliability growth after 9-11. In the next section we will investigate whether SS7 outages follow a similar trend model. These results differ from the smooth decrease per year that ATIS published.

### 5.2 Reliability: SS7 outage Laplace trend test results

In this section the Laplace trend test was used to examine trends for SS7 outages over two different time periods: 1999-2000 and 2003-2004. The results are shown in Table 2.

<table>
<thead>
<tr>
<th>Years</th>
<th>$U$</th>
<th>P-value</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>99-00</td>
<td>1.503</td>
<td>.133</td>
<td>Possible increasing trend</td>
</tr>
<tr>
<td>03-04</td>
<td>-1.515</td>
<td>.129</td>
<td>Possible decreasing trend</td>
</tr>
</tbody>
</table>

The inference of trends is not strong as a critical value of 0.10 would lead to accepting the Null Hypothesis of no trend during either time period. However, if the critical value were 0.15, we would accept trends. Furthermore, the positive value of “$U$” for 1999-2000 would indicate reliability deterioration while the negative value of “$U$” in 2003-2004 would indicate reliability growth. This test implies that that both the HHP and NHPP models should be investigated.

### 5.3 Reliability: Poisson models for SS7 outages

This section contains separate models for 1999-2000 (before 9-11) and 2003-3004 (after 9-11). Poisson regression was performed with the passage of time as the explanatory variable.
value. Results are shown in Table 3 and the models plotted in Figure 14. These models indicate reliability deterioration and reliability growth. Likewise, Poisson regression was performed without time as an explanatory. These results are shown in Table 4 and Figure 15.

### Table 3. Reliability growth and deterioration model results

<table>
<thead>
<tr>
<th>Period</th>
<th>Model</th>
<th>P-Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999-2000</td>
<td>( \log \mu_i = 1.0272 + 0.0234 \cdot t_i ) ( \mu_i = 2.86 \cdot \exp(0.286 \cdot t) )</td>
<td>Constant: 0.0000+, Time ( t_i ) : 0.139</td>
</tr>
<tr>
<td>2003-2004</td>
<td>( \log \mu_i = 1.1703 - 0.0288 \cdot t_i ) ( \mu_i = 1.16 \cdot \exp(-0.0288 \cdot t) )</td>
<td>Constant: 00000+, Time ( t_i ) : 0.157</td>
</tr>
</tbody>
</table>

![Figure 14. SS7 Reliability growth and deterioration models](image-url)
Table 4. Reliability constancy model results

<table>
<thead>
<tr>
<th>Period</th>
<th>Model</th>
<th>P-Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999-2000</td>
<td>$\log \mu_i = 1.3328$ $\mu_i = 3.79$</td>
<td>Constant: 0.0000+</td>
</tr>
<tr>
<td>2003-2004</td>
<td>$\log \mu_i = 0.82928$ $\mu_i = 2.29$</td>
<td>Constant: 00000+</td>
</tr>
</tbody>
</table>

Figure 15. SS7 jump point model

The significances of these models are similar to that indicated by the Laplace trend tests. Based upon these models, we accept the Laplace trend test Null Hypothesis, and the models showing constant, but different, outage count models.
5.4 Visual survivability assessment

In order to answer any pre and post differences in survivability metrics (customers affected, total customers affected duration & blocked calls before and after 9-11), a visual examination was made of time series plots.

5.4.1 Access line time series plots

A plot of access lines (which is customers affected) and time of the outage is seen in Figure 16 is. From the plot, it seems that the maximum customers affected have reduced after 9-11. In addition, there seems to be less variance in access lines after 9-11. A cumulative plot of access line vs. time is shown in Figure 17. The total number of access lines has reduced after 9-11, there has been survivability growth after 9-11.

Figure 16. Access lines vs. time of outage
5.4.2 Blocked calls time series plots

A plot of blocked calls versus time of the outage is seen in Figure 18. From the plot, it seems that the maximum value for the blocked calls have reduced after 9-11. In addition there is less variance in blocked calls after 9-11 as opposed to before 9-11. A cumulative plot of blocked calls vs. time is seen in Figure 19. The number of blocked calls has reduced after 9-11, thus there is a survivability growth after 9-11.
Figure 18. Blocked calls vs. time of outage

Figure 19. Cumulative plot of blocked calls vs. time
5.4.3 Duration time series plots

A plot of duration and time of the outage is displayed in Figure 20. From the plot, it seems that the maximum outage duration has reduced after 9-11. In addition, there is less variance in duration after 9-11. A cumulative plot of duration vs. time is shown in Figure 21. As the total duration has reduced after 9-11 thus there is a survivability growth after 9-11.

![Figure 20. Duration (min) vs. time of the outage](image-url)
5.4.4 Total customers affected vs. time of outage

A plot between total customers affected and time of the outage is seen in Figure 22. This metric combines customers affected and one-third of blocked calls. From the plot, it seems that the maximum value for the total customers affected have reduced after 9-11. Also, there is less variance in total customers affected after 9-11 as opposed to before 9-11. A cumulative plot of total customers affected vs. time is shown in Figure 23. As the number of total customers affected has reduced after 9-11, there is a survivability growth after 9-11.
Figure 22. Total customers affected vs. time of the outage

Figure 23. Cumulative plot of total customers affected vs. time
5.5 Descriptive analysis

In order to further analyze the differences in the customers affected, blocked calls, duration, and total customers affected, descriptive analysis was performed.

The descriptive analysis of access lines are summarized in Table 5. The mean value of access lines lost is smaller after 9-11. However, median is slightly larger. Access line histograms are shown in Figures 24 and 25, where the curve indicates a truncated normal distribution.

Table 5. Descriptive analysis of access lines affected

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>99-00</td>
<td>815,267</td>
<td>8,238</td>
<td>47,956</td>
</tr>
<tr>
<td>03-04</td>
<td>449,000</td>
<td>66,940</td>
<td>43,863</td>
</tr>
</tbody>
</table>
Figure 24. Outage event access line distribution (99-00)
The descriptive statistics for Blocked calls are summarized in Table 6. The mean value of Blocked calls has reduced after 9-11. However, the median seems to increase. Blocked Call histograms are shown in Figures 26 & 27.

**Figure 25. Outage event access line distribution (03-04)**

**Table 6. Descriptive statistics for blocked calls**

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>99-00</td>
<td>3,012,515</td>
<td>179,448</td>
<td>42,613</td>
</tr>
<tr>
<td>03-04</td>
<td>2,518,803</td>
<td>172,978</td>
<td>108,031</td>
</tr>
</tbody>
</table>
Figure 26. Outage event blocked call distribution (99-00)
Figure 27. Outage event blocked call distribution (03-04)

The descriptive statistics for duration are summarized in Table 7. The mean and the median values for duration have increased. Duration histograms are shown in Figures 28 & 29.

Table 7. Descriptive statistics for duration (in hrs)

<table>
<thead>
<tr>
<th>Year</th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>99-00</td>
<td>19.25</td>
<td>2.975</td>
<td>1.54</td>
</tr>
<tr>
<td>03-04</td>
<td>14</td>
<td>3.20</td>
<td>1.98</td>
</tr>
</tbody>
</table>
Figure 28. Outage event duration distribution (99-00)
Figure 29. Outage event duration distribution (03-04)

The descriptive statistics for total Customers Affected are summarized in Table 8. The mean value of Total customers affected has reduced after 9-11. However, median seems to increase. Total customers affected histograms are shown in Figures 30 & 31.

Table 8. Descriptive statistics for total customers affected

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>99-00</strong></td>
<td>1,593,947</td>
<td>142,197</td>
<td>67,520</td>
</tr>
<tr>
<td><strong>03-04</strong></td>
<td>889,601</td>
<td>124,599</td>
<td>84,633</td>
</tr>
</tbody>
</table>
Figure 30. Outage event total customers affected distribution (99-00)
Figure 31. Outage event total customers affected distribution

5.6 Comparison of means

In order to understand the significance of the observed differences in mean obtained in descriptive analysis, t-tests were performed. The summarized results are displayed in Table 9.

Table 9. Difference in means test results

<table>
<thead>
<tr>
<th>Variables</th>
<th>T stat value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access line</td>
<td>0.519</td>
<td>0.604</td>
</tr>
<tr>
<td>Blocked calls</td>
<td>-0.984</td>
<td>0.327</td>
</tr>
<tr>
<td>Variables</td>
<td>T stat value</td>
<td>P-value</td>
</tr>
<tr>
<td>--------------------------</td>
<td>--------------</td>
<td>---------</td>
</tr>
<tr>
<td>Duration</td>
<td>-1.487</td>
<td>0.139</td>
</tr>
<tr>
<td>Total no. of customers affected</td>
<td>-0.694</td>
<td>0.489</td>
</tr>
</tbody>
</table>

Since the t-stat values for all the variables are between +2 and -2, we cannot reject the null hypothesis that there is no difference in the variables before and after 9-11 at a critical value of 0.10.

5.7 Temporal analysis

5.7.1 Time of day analysis

In order to analyze the time of the day, time was divided into six time slots of four hours each:

- 12 A.M to 4 A.M.
- 4 A.M to 8 A.M.
- 8 A.M to 12 P.M.
- 12 P.M to 4 P.M.
- 4 P.M to 8 P.M
- 8 P.M to 12 A.M.

Actually, the slots are mutually exclusive, e.g. 12 am -3:59 am, 4 am to 7:59 am, etc. However, they are referred to as listed above.

Pre and post 9-11 outage start times were sorted into the time slots and the percentage distribution is shown in Figure 32. The number of outages has reduced after 9-11 in time slot 12am-4am, 4am-8am, and 8am-12pm but they seem to increase in 12pm-4pm, 4pm-
8pm, and 8pm-12am. Moreover, the maximum number of outages is observed in the 8 am – 12 pm slot pre and post 9-11. Also, a major difference is seen in the 8 pm- 12 pm slot.

In order to analyze the difference in the time of day slots before and after 9-11 an ANOVA test was performed on the data shown in Figure 32. The results of ANOVA test is shown in Table 10.

**Figure 32. Distribution of events into time slots before and after 9-11**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>12 AM - 4 AM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 AM - 8 AM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 AM - 12 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 PM - 4 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 PM - 8 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 PM - 12 AM</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 10. Results of ANOVA test for time of the day**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>F</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rows</td>
<td>2.7</td>
<td>0.14</td>
</tr>
<tr>
<td>Columns</td>
<td>0.0</td>
<td>0.99</td>
</tr>
</tbody>
</table>
Significantly high p-value for rows and columns in Table 11 weakly indicates that there is a difference in events amongst different time slots. However, we conclude very strongly that there is no difference between the distribution of events over the day before and after 9-11 respectively.

5.7.2 Day of the week analysis

Comparison of day of week before and after 9-11 is shown in a bar chart in Figure 33.

In order to analyze the difference in the day of week before and after 9-11 ANOVA test was performed on the data in Figure 33. The results of ANOVA test is shown in Table 11.
Table 11. Results of ANOVA test for day of week

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>F</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rows</td>
<td>1.924</td>
<td>0.223</td>
</tr>
<tr>
<td>Columns</td>
<td>0.0</td>
<td>0.993</td>
</tr>
</tbody>
</table>

Significantly high p-value indicates that there is no difference between the day of week event distribution before and after 9-11. Comparison of weekdays/weekend before and after 9-11 is shown in a bar chart in Figure 34.

![Bar chart showing comparison of SS7 outages before and after 9-11](image)

**Figure 34. Comparison for the weekday/weekend before and after 9-11**

The bar chart indicates that most SS7 outages occur during weekdays as opposed to weekend in both pre and post 9-11 events. However weekend outages after 9-11 did not decrease.
5.8 Causality analysis

Causality analysis consisted of looking for any:

- Outage count differences in three causality types (trigger, direct, and root) and the casual type categories introduced in 4.5. The graphs in Appendix B were used for this analysis.

- Survivability metric differences in three causality types (trigger, direct, and root) and the casual type categories introduced in 5.4.

The survivability metrics and the source data for the analysis are listed below:

- Outage duration (Appendix C)
- Isolated access lines (Appendix D)
- Blocked calls (Appendix E)
- Total customers affected (Appendix F)
- Outage Impact (Appendix G)
- Events by day of week (Appendix H)
- Events by daily time slot (Appendix I)
- Impact by day of Week (Appendix J)
- Impact by daily time slot (Appendix K)

A summary of the strength of pre and post percent distribution differences for each measure and causes are shown in Table 12. Percent distribution differences between pre and post 9-11 are categorized as little, some, or moderate, based upon the following criteria:

- Little difference : Less than 5% difference
- Some difference: 5 to 15%
• Moderate difference: 15% to 35%

Also, the differences are expressed as positive or negative depending on increase or decrease in percent distribution respectively after 9-11. Causality differences between pre and post 9-11 were found, in major categories. A summary of which are:

• Little : 4 instances
• Some : 16 instances
• Moderate : 10 instances

More significant differences were found in the casual subcategories. These are also noted in Table 12.
<table>
<thead>
<tr>
<th>Measure</th>
<th>Trigger Cause</th>
<th>Direct Cause</th>
<th>Root Cause</th>
</tr>
</thead>
</table>
| Outage Count (Appendix B) | • Little difference | • Some difference  
• In A-link subcategory, about +10% difference in A-link clock failures | • Some difference  
• About -12% difference due to procedural errors  
• About +10% difference due to diversity deficits |
| Outage Duration (Appendix C) | • Moderate difference  
• About -20% difference triggered by fiber cuts  
• About a +10% difference triggered by equipment failure | • Moderate difference  
• About -15% difference due to A-link loss  
• In A-Link subcategories, -27% difference due to loss of point to point A-links; About a +20% difference due to clock and local switch A-link interface failures collectively | • Moderate difference  
• In diversity deficit subcategories, about -20% difference due to A-link diversity deficits  
• About a +20% difference due to equipment single point of failure |
| Isolated Access Lines (Appendix D) | • Moderate differences  
• About a +15% difference triggered by human activity | • Moderate differences  
• About a +10% difference each due to SCP and STP failures  
• About a -15% and -10% differences due to SS7 process failures and SS7 network failures, respectively.  
• In the A-link subcategories, there is a -10% difference | • Moderate differences  
• In the diversity deficient subcategories, about a -20% difference due to lack of A-link diversity, about +25% difference due to lack of power diversity and -20% difference due to single points of failure. Additionally, -20% difference due to lack of D-link diversity. |
<table>
<thead>
<tr>
<th>Measure</th>
<th>Trigger Cause</th>
<th>Direct Cause</th>
<th>Root Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocked Calls (Appendix E)</td>
<td>• Moderate difference</td>
<td>• Some difference</td>
<td>• Moderate differences</td>
</tr>
<tr>
<td></td>
<td>• About +30% difference triggered by human activity and about +35% difference due to equipment failure</td>
<td>• About -5% difference due to A-link loss</td>
<td>• About +25% difference due to procedural error</td>
</tr>
<tr>
<td></td>
<td>• About -6% difference triggered by overload.</td>
<td>• In A-link subcategory, about -12% difference due to lack of A-link diversity</td>
<td>• About -20% difference due to design errors and about -5% difference due to diversity deficits.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• About +10% difference due to switch interface failure</td>
<td>• In the diversity deficit subcategory, -10% difference due to A-link diversity deficits and +20% difference due to power diversity deficits.</td>
</tr>
<tr>
<td>Total Customers Affected (Appendix F)</td>
<td>• Moderate differences</td>
<td>• Moderate difference</td>
<td>• Moderate difference</td>
</tr>
<tr>
<td></td>
<td>• About +20% difference triggered by human activity</td>
<td>• In A-link subcategories, about -10% difference due to loss of point to point A-links and about +20% difference due to A-link clock</td>
<td>• About -10% difference due to diversity deficit</td>
</tr>
<tr>
<td></td>
<td>• About +15% difference triggered by equipment failure</td>
<td></td>
<td>• Diversity deficit subcategories:, -20% difference due to lack of A-link diversity, -10% difference due to D-link failures, +20% difference due to power diversity deficits, and +15% difference due to single points of failure.</td>
</tr>
<tr>
<td>Outage Impact (Appendix G)</td>
<td>• Moderate differences</td>
<td>• Some difference</td>
<td>• Some differences</td>
</tr>
<tr>
<td></td>
<td>• About -20% difference triggered</td>
<td>• About -10% difference due to A-link loss ,</td>
<td>• About +10% difference due to procedural errors</td>
</tr>
<tr>
<td>Measure</td>
<td>Trigger Cause</td>
<td>Direct Cause</td>
<td>Root Cause</td>
</tr>
<tr>
<td>----------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>by fiber cuts</td>
<td>• About +10% difference due to STP failure</td>
<td>• Some difference</td>
</tr>
<tr>
<td></td>
<td>• About +12% difference each triggered by human activity, and equipment failure</td>
<td></td>
<td>• About +10 to +15% difference due to diversity deficit on Thursday</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• About -0 to -5% difference in procedural error throughout the week</td>
</tr>
<tr>
<td>Day of week (Appendix I)</td>
<td>• Some difference</td>
<td>• Some difference</td>
<td>• Some difference</td>
</tr>
<tr>
<td></td>
<td>• About +5 to +8% difference triggered by equipment failure on Wednesday and</td>
<td>• About +8 to +12% difference due to A-link loss on Sunday and a +0 to +4% difference due to STP failure and SS7-network failure throughout the week</td>
<td></td>
</tr>
<tr>
<td></td>
<td>about +5 to +8% difference by fiber cuts on Thursday</td>
<td></td>
<td>• About -4 to -8% difference due to A-link loss on Friday, and about -4 to -8% difference due to SS7-Process on Saturday</td>
</tr>
<tr>
<td></td>
<td>• About -3 to -5% difference in human activity and equipment failure on</td>
<td></td>
<td>• Some difference</td>
</tr>
<tr>
<td></td>
<td>Fridays and Saturday</td>
<td></td>
<td>• About +10 to +15% difference due to diversity deficit on Thursday</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• About -0 to -5% difference in procedural error throughout the week</td>
</tr>
<tr>
<td>Time Slot (Appendix J)</td>
<td>• Some difference</td>
<td>• Some difference</td>
<td>• Some difference</td>
</tr>
<tr>
<td></td>
<td>• About +5 to +8% difference triggered by fiber cuts in 4pm-8pm slot and</td>
<td>• About +5 to +8% difference due to A-link loss in 12pm-4pm slot and 8pm-12am slot</td>
<td>• About +6 to +9% difference due to diversity deficit in 8am-12am slot</td>
</tr>
<tr>
<td></td>
<td>8pm-12am slot</td>
<td></td>
<td>• About -3 to -6% difference in 8am-12pm slot, and -3 to -6% difference due to procedural error in 12am-4am slot, 4pm-8pm slot and 8pm-12am slot</td>
</tr>
<tr>
<td></td>
<td>• About -3 to -5% difference triggered by equipment failures in 8am-12pm slot</td>
<td></td>
<td>• About -3 to -6% difference in diversity deficit in 8am-12pm slot, and -3 to -6% difference due to procedural error in 12am-4am slot, 4pm-8pm slot and 8pm-12am slot</td>
</tr>
<tr>
<td>Measure</td>
<td>Trigger Cause</td>
<td>Direct Cause</td>
<td>Root Cause</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>-3 to -5% difference by human activity on 4am-8am slot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekly Impact</td>
<td>• Moderate difference</td>
<td>• Moderate difference</td>
<td>• Some difference</td>
</tr>
<tr>
<td>(Appendix K)</td>
<td>• About +15% difference triggered by equipment failure on Thursday</td>
<td>• About +18% difference due to A-link loss on Thursday</td>
<td>• About +12% difference due to diversity deficit on Thursday</td>
</tr>
<tr>
<td></td>
<td>• About -10% difference triggered by fiber cuts on Wednesday</td>
<td>• About -18% difference due to A-link loss on Wednesday</td>
<td>• About -12% difference due to diversity deficit on Tuesday</td>
</tr>
</tbody>
</table>
5.8.1 Examples of differences in major casual categories (pre and post)

Examples of little, some and moderate differences in major casual categories are shown and discussed below.

- Trigger cause percent event distribution (little)
- Direct cause percent blocked call distribution (little)
- Root cause percent event distribution (some)
- Root cause percent impact distribution (some)
- Trigger cause percent blocked call distribution (moderate)
- Root cause percent blocked call distribution (moderate)

A plot indicating little trigger cause difference is seen in Figure 35, where the percentage distribution of outage events and trigger causes is graphed. From this chart it seems there is a slight reduction in outage percent distribution difference due to fiber cut, human activity and power source while a slight increase is observed in outage percent distribution difference due to environmental factors and unknown causes.
Another plot indicating little direct cause differences is seen in Figure 36 where the percent distribution of blocked calls and direct causes is graphed. From this chart it seems that there is slight reduction in blocked calls percent distribution difference due to SCP failure and A-link loss, while there is a slight increase is observed in blocked calls percent distribution difference due to STP failure, SS7 Network failure, and SS7 Process failure.
Figure 36. Direct cause: percent blocked calls distribution (pre and post 9-11)

A plot indicating some root cause differences is seen in Figure 37 where the percent distribution of outage events and root causes is graphed. From this chart it seems that there is some reduction in outage percent distribution difference due to procedural errors while some increase is observed in outage percent distribution difference due to diversity deficit.
Another plot indicating some root cause differences is seen in Figure 38 where the percent distribution of impact and root causes is graphed. From this chart it seems that there is some increase in impact percent distribution difference due to procedural errors.
A plot indicating moderate trigger cause differences is seen in Figure 39 where the percent distribution of blocked calls and trigger causes is graphed. From this chart it seems that there is moderate increase in blocked calls percent distribution difference due to human activity while a moderate decrease is observed in blocked calls percent distribution difference due to equipment failure.

Figure 39. Trigger cause: percent blocked calls distribution (pre and post 9-11)

Another plot indicating some root cause differences is seen in Figure 40 where the percent distribution of outage events and root causes is graphed. From this chart it seems that there is moderate increase in blocked calls percent distribution difference due to procedural error while a moderate decrease is observed in blocked calls percent distribution difference due to design error and diversity deficit.
5.8.2 Examples of differences in subcategories (pre and post)

Some examples of differences in subcategories are also shown and discussed.

- Diversity deficit sub root cause distribution for total customers affected (moderate)
- A-link sub direct cause distribution of isolated access lines (moderate)

A plot indicating moderate diversity deficit sub root cause distribution differences are seen in Figure 41 for total customers affected. From this chart it seems that there is moderate increase in total customers affected percent distribution difference due to power diversity deficit and single point of failure while a moderate decrease is observed in total customers affected percent distribution difference due to A-link diversity deficit.
A plot indicating moderate A-link sub direct cause distribution differences is seen in Figure 42 where the percent A-link sub causes for isolated access lines are graphed. From this chart it seems that there is moderate increase in total customers affected percent distribution difference due to A-link clock.
Overall the pre and post metric differences in major causal categories was not large. Taking this into consideration and the finding that outage rates were different, but constant in each time period, a decision was made to pool the data and analyze causality for the entire data set. Causality percent distribution for the total sample is shown in Table 13. The results in this table were derived from an analysis of the plots in the aforementioned appendices.

For the pooled data, the impact of SS7 outages were categorized as low, medium, or high impact:

- Low impact: less than 250,000 lost line hours
- Medium impact: greater than or equal to 250,000 and less than 1,000,000 lost line hours
- Moderate: greater than or equal than 1,000,000 lost line hours

These results can be found in Appendix H
Table 13. Observed causality in total sample

<table>
<thead>
<tr>
<th>Measure</th>
<th>Trigger Cause</th>
<th>Direct Cause</th>
<th>Root Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outage Count (Appendix B)</td>
<td>• About 83% is due to three trigger causes which are human activity (38%), followed by equipment failure (25%) and fiber cuts (20%)</td>
<td>• About 77% is due to A-link loss and about 12% due to SS7 switch process</td>
<td>• About 50% is due to diversity deficits</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Of the A-link subcategories, about 50% is due to loss of point to point A-links, about 20% due to loss of A-link clock, and about 16% due to A-link switch interface</td>
<td>• About 25% are due to procedural errors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• In the diversity deficit subcategories, about 67% is due to lack of diversity for point to point A-links, about 20% due to power diversity deficits, and about 12% due to single point of failure</td>
</tr>
<tr>
<td>Outage Duration (Appendix C)</td>
<td>• About 35% is triggered by fiber cuts, about 25% by human activity, and 25% by equipment failures</td>
<td>• About 80% is due to A-link loss</td>
<td>• About half is due to diversity deficit and about 20% each due to procedure and design errors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In A-Link subcategory, about 70% is due to point to point link loss, about 10% is due to loss of A-link clock, and 10% due to switch interface.</td>
<td>• In diversity deficit subcategories, about 80% is due to lack of A-link diversity</td>
</tr>
<tr>
<td>Isolated Access Lines (Appendix D)</td>
<td>• About 35% each are triggered by equipment failure and human activity, and about 15% due to fiber cut</td>
<td>• About 70% is due to loss of A-links</td>
<td>• About 60% are due to diversity deficit, and about 20% due to procedural error</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Subcategory About 50% is due to point to point A-links, and about 20% due to A-link clock</td>
<td>• In diversity deficit subcategories, about 50% is due to lack of A-link diversity, and about 18% due to power</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measure</td>
<td>Trigger Cause</td>
<td>Direct Cause</td>
<td>Root Cause</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Blocked Calls (Appendix E)</td>
<td>About 35% is triggered by equipment failures, about 30% by human activity and 15% by fiber cuts</td>
<td>About 50% are due to A-link loss, and about 35% due to SCP failure</td>
<td>About 40% is due to diversity deficits, about 30% due to design errors, and about 25% due to procedural errors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In A-link subcategories, about 80% is due to point to point A-links, and about 10% due to A-link clock</td>
<td>Of the diversity deficits, 80% due to A-link diversity deficits and 10% due to lack of power diversity.</td>
</tr>
<tr>
<td>Total Customers Affected (Appendix F)</td>
<td>About 35% are triggered by equipment failures, about 30% by human activity, and about 15% by fiber cuts</td>
<td>About 65% are due to A-link loss, and about 20% due to SCP failure</td>
<td>About 50% is due to diversity deficits, and about 20% each due to design and procedural errors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In A-link subcategories, about 60% are due to point to point A-links, and about 15% due to A-link clock</td>
<td>Of the diversity deficits, about 60% due to A-link diversity deficits and 15% due to lack of power diversity.</td>
</tr>
<tr>
<td>Outage Impact (Appendix G)</td>
<td>About 40% is triggered by equipment failure, about 30% by fiber cuts, and about 20% by human activity</td>
<td>About 65% is due to A-links loss and about 20% due to SCP failure</td>
<td>About 50% is due to diversity deficit, about 25% due to design errors, and about 15% due to procedural errors</td>
</tr>
<tr>
<td>Impact Severity: About 64% of outages are low impact,</td>
<td>In low impact category, about 30% are triggered by human activity, about 20% by equipment failure and about 7% by fiber cut</td>
<td>In low impact category, about half are due to A-link loss and about 10% due to SS7 process</td>
<td>In low impact category, about 30% are due to diversity deficit and about 20% due to procedural error</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In medium impact</td>
<td>In medium impact</td>
</tr>
<tr>
<td>Measure</td>
<td>Trigger Cause</td>
<td>Direct Cause</td>
<td>Root Cause</td>
</tr>
<tr>
<td>---------</td>
<td>---------------</td>
<td>--------------</td>
<td>------------</td>
</tr>
</tbody>
</table>
| 20% are medium impact and 15% are high impact (Appendix H) | • In medium impact category, about 7% are triggered by fiber cut and about 5% by human activity  
• In high impact category, about 5% each are triggered by fiber cut and equipment failure | category, about 20% are due to A-link loss  
• In high impact category, about 10% are due to A-link loss | about 10% are due to diversity deficit and about 5% are due to design error  
• In high impact category, about 8% are due to diversity deficit and about 5% due to design error |

| Events by Day of Week (Appendix I) | • About 8-10% are triggered by human activity on Wednesday and about 6-8% each by fiber cut and equipment failure on Wednesday and Thursday  
• Human activity triggers minimal outages on weekend (0-2%)  
• Power, overload, environmental and unknown trigger events are minimal (0-2%) throughout the week | • About 16-20% is due to A-link loss on Wednesday and about 12-16% due to A-link loss on Tuesday and Thursday  
• A-link loss on the weekend is minimal (0-4%)  
• Distribution of SCP failure, STP failure, SS7 network failure and SS7 process failure are evenly spread (0-4%) throughout the week | • About 10-13% due to diversity deficit is on Wednesday, about 8-10% of diversity deficit is on Tuesday and about 5-8% is on Thursday  
• Distribution of procedural error is about 3-5% until Saturday and on Sunday it reduces to 0-3%  
• Facility maintenance and design error are fairly constant (0-3%) throughout the week |

| Events by Time Slot (Appendix J) | • About 0-2% is triggered by fiber cut in 12am-4am slot and 4am-8am slot. It then increases to 8-10% in the 8am-12pm slot and finally reduces to 2-4% towards midnight | • About 16-20% each is due to A-link loss in 12am-4am and 8am-12pm slot  
• SCP failure, STP failure, SS7 network failure, SS7 process failure and unknown is fairly constant | • About 12-15% is due to diversity deficit in the 8am-12pm slot  
• Distribution due to procedural error is fairly constant (0-3%) in all the time slots |
<table>
<thead>
<tr>
<th>Measure</th>
<th>Trigger Cause</th>
<th>Direct Cause</th>
<th>Root Cause</th>
</tr>
</thead>
</table>
| • About 8-10% is triggered by human activity in the 12am-4am slot which further reduces to 0-2% towards midnight  
• Distribution due to power, overload, environmental and unknown is fairly constant (0-2%) in all the time slots | (0-4%) in all the time slots | |
5.8.3 Examples of causality in major causal categories (pooled sample)

Examples of casual distribution for pre and post data (polled) are shown and discussed below.

- Trigger cause percent distribution by day of week
- Direct cause percent distribution by impact severity
- Trigger cause percent distribution by time of day
- Root cause percent distribution by time of day

A plot indicating total sample causality percent distribution is seen in Figure 43, where the percent distribution of event day of week and trigger causes is graphed. From this Figure it seems that most outages are triggered by human activity on Wednesday followed by some due to fiber cut and equipment failure on Wednesday and Thursday. Also, it seems that outages due to fiber cut, human activity, and equipment failure are lower on weekends.
Figure 43. Trigger cause: percent day of week distribution (pooled)

A plot indicating total sample causality percent distribution is seen in Figure 44, where the percent distribution of impact severity and direct causes is graphed. From this figure it seems that most outages are low impact. Most of the low impact outages are due to A-link loss. Some outages are medium impact which is mostly due to A-link loss. Very few outages are high impact.
A plot indicating total sample causality percent distribution is seen in Figure 45, where the percent distribution of time slot and trigger causes is graphed. From this Figure 45, it seems that most outages are triggered by human activity in 12am-4am slot and due to fiber cut on 8am-12pm. Also, it seems that outages due to fiber cut, human activity, and equipment failure are lower at midnight.
Figure 45. Trigger cause: percent time slot distribution (pooled)

Another plot indicating total sample causality percent distribution is seen in Figure 46, where the percent distribution of time slot and root causes is graphed. From this figure it seems that most outages are due to diversity deficit in the 8am-12pm slot. Also, distribution due to procedural error, facility maintenance, and design error are equally spread in all the slots.
5.8.4 Examples of causality in subcategories (pooled sample)

Examples of casual subcategory distribution for the pooled data are shown and discussed below.

- Diversity deficit sub root cause percent distribution for duration
- A-link sub direct cause percent distribution of blocked calls

A plot indicating total sample subcategory causality percent distribution is seen in Figure 47, where the percent diversity deficit sub root cause distribution for duration is graphed. From this figure it seems that most of the high duration outages are due to A-link diversity deficit followed by some of the duration due to single points of failure.
Figure 47. Sub root cause: percent diversity duration distribution (pooled)

A plot indicating total sample causality subcategory percent distribution is seen in Figure 48 where the percent A-link sub direct cause distribution of blocked calls is graphed. From this figure it seems that most of the blocked calls are due to direct A-link loss followed by some due to A-link clock failure.

Figure 48. Sub direct cause: percent A-link blocked calls distribution (pooled)
5.8.5 Results of causality analysis by frequency

A search was made for the frequency of outages that had the same trigger, direct, and root causes. The results are displayed in the Table 15.

Out of 210 (7x6x5) possible trigger-direct-root cause combinations, 145 outage events used but 36 unique causality combinations. Some are common to pre and post, and the numbers of unique combinations are:

- Pre: 23
- Post: 25

These do not add to 36 because of common combinations. From this we conclude the combinations are spread pretty evenly in pre and post 9-11.

The *increase* in the top five casual combinations of the post 9-11 events are:

- Human activity – A-link loss – Diversity deficit (4)
- Fiber cut – A-link loss – Diversity deficit (-7)
- Equipment failure – A-link loss – Diversity deficit (1)
- Human activity – A-link loss – Procedural error (-13)
- Overload – A-link loss – Facility maintenance (2)

Most of the post and pre 9-11 outages were triggered by human activity, followed by fiber cut, and equipment failure. Amongst direct causes the prevalent direct cause was A-link loss in both pre and post 9-11 events. Also, some instances of overload were observed in post 9-11 unlike pre 9-11 events. Most of the pre 9-11 root causes were
procedural error as opposed to diversity deficit in post 9-11 events (see Table 14 and Table 17)

Further, maximum decrease in post 9-11 event was observed in human activity – A-link loss – Procedural Error combination. In addition, some reduction in post 9-11 outages were in Fiber Cut – A-link loss – Diversity Deficit combination and Human Activity – SS7-Process – Procedural Error combination. In contrast some increase in post 9-11 outages were discovered in Human Activity – A-link loss – Diversity Deficit combination. Besides this more reliability growth was observed in post 9-11 outages than reliability deterioration (see Table 14 where R stands for reliability and D for deterioration)

For the entire polled dataset, the top five casual combinations are:

- Fiber cut – A-link loss – Diversity deficit (25)
- Human activity – A-link loss – Procedural error (23)
- Human activity – A-link loss – Diversity deficit (18)
- Equipment failure – A-link loss – Diversity deficit (13)
- Human activity – SS7-Process – Procedural error (8)

Most of the outages in the pooled sample were triggered by fiber cut followed by some due to human activity and equipment failure. Most common direct cause was A-link loss followed by some outages due to SS7-Process. The prevalent root cause in the polled dataset was diversity deficit and procedural error.
### Table 14. Results of causality frequency

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Direct</th>
<th>Root</th>
<th>Total Outages</th>
<th>Pre 9-11 Outages</th>
<th>Post 9-11 Outages</th>
<th>Difference (Pre-Post)</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Activity</td>
<td>A-Link Loss</td>
<td>Procedural Error</td>
<td>23</td>
<td>18</td>
<td>5</td>
<td>13</td>
<td>G</td>
</tr>
<tr>
<td>Fiber Cut</td>
<td>A-Link Loss</td>
<td>Diversity Deficit</td>
<td>25</td>
<td>16</td>
<td>9</td>
<td>7</td>
<td>G</td>
</tr>
<tr>
<td>Human Activity</td>
<td>SS7-Process</td>
<td>Procedural Error</td>
<td>8</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>G</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>A-Link Loss</td>
<td>Design Error</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>G</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>SS7-Process</td>
<td>Facility Maintenance</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>G</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>SS7-Process</td>
<td>Design Error</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>G</td>
</tr>
<tr>
<td>Power Source</td>
<td>A-Link Loss</td>
<td>Diversity Deficit</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>G</td>
</tr>
<tr>
<td>Environmental Error</td>
<td>A-Link Loss</td>
<td>Diversity Deficit</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>G</td>
</tr>
<tr>
<td>Fiber Cut</td>
<td>A-Link Loss</td>
<td>Facility Maintenance</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>G</td>
</tr>
<tr>
<td>Overload</td>
<td>SCP failure</td>
<td>Design Error</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>G</td>
</tr>
<tr>
<td>Human Activity</td>
<td>A-Link Loss</td>
<td>Design Error</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>G</td>
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<tr>
<td>Overload</td>
<td>A-Link Loss</td>
<td>Design Error</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>G</td>
</tr>
<tr>
<td>Unknown</td>
<td>A-Link Loss</td>
<td>Diversity Deficit</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>G</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>SCP failure</td>
<td>Design Error</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>G</td>
</tr>
<tr>
<td>Power Source</td>
<td>A-Link Loss</td>
<td>Facility Maintenance</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>G</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>STP failure</td>
<td>Diversity Deficit</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>G</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>SS7-Network</td>
<td>Diversity Deficit</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>G</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>A-Link Loss</td>
<td>Unknown</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>G</td>
</tr>
<tr>
<td>Fiber Cut</td>
<td>A-Link Loss</td>
<td>Unknown</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>G</td>
</tr>
<tr>
<td>Human Activity</td>
<td>SCP failure</td>
<td>Procedural Error</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>G</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>A-Link Loss</td>
<td>Facility Maintenance</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>G</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>A-Link Loss</td>
<td>Diversity Deficit</td>
<td>13</td>
<td>6</td>
<td>7</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Human Activity</td>
<td>STP Failure</td>
<td>Procedural Error</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Human Activity</td>
<td>SS7-Network</td>
<td>Procedural Error</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Environmental Error</td>
<td>A-link Loss</td>
<td>Facility Maintenance</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Environmental Error</td>
<td>SS7-Process</td>
<td>Facility Maintenance</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>STP Failure</td>
<td>Design Error</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Fiber Cut</td>
<td>A-link Loss</td>
<td>Design Error</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Trigger</td>
<td>Direct</td>
<td>Root</td>
<td>Total Outages</td>
<td>Pre 9-11 Outages</td>
<td>Post 9-11 Outages</td>
<td>Difference (Pre-Post)</td>
<td>Reliability</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>---------------</td>
<td>-----------------</td>
<td>------------------</td>
<td>----------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Unknown</td>
<td>SS7-Process</td>
<td>Design Error</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>Unknown</td>
<td>Design Error</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Fiber Cut</td>
<td>SS7-Network</td>
<td>Diversity Deficit</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Unknown</td>
<td>A-link Loss</td>
<td>Unknown</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Unknown</td>
<td>SS7-Network</td>
<td>Unknown</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Overload</td>
<td>A-link Loss</td>
<td>Unknown</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>D</td>
</tr>
<tr>
<td>Overload</td>
<td>A-link Loss</td>
<td>Facility Maintenance</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>-2</td>
<td>D</td>
</tr>
<tr>
<td>Human Activity</td>
<td>A-Link Loss</td>
<td>Diversity Deficit</td>
<td>18</td>
<td>7</td>
<td>11</td>
<td>-4</td>
<td>D</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>145</strong></td>
<td></td>
<td><strong>90</strong></td>
<td><strong>55</strong></td>
<td><strong>35</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Outage frequency distribution for trigger causes is shown in Table 15. From the table it seems that there is reliability growth after 9-11 in trigger cause in almost all the categories with the maximum reliability growth in human activity (about 15 outages). Also, when we look at total outages it seems that the human activity is the primary trigger cause for SS7 outages. Even though there seems an improvement in human activity category it is still a big concern because maximum number of outages in post 9-11 events is due to human activity.

<table>
<thead>
<tr>
<th>Trigger Causes</th>
<th>Total Outages</th>
<th>Pre 9-11 Outages</th>
<th>Post 9-11 Outages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Activity</td>
<td>55</td>
<td>35</td>
<td>20</td>
</tr>
<tr>
<td>Equipment Failure</td>
<td>37</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>Fiber Cut</td>
<td>30</td>
<td>19</td>
<td>11</td>
</tr>
<tr>
<td>Power Source</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Overload</td>
<td>7</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Environment Error</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Unknown</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>145</strong></td>
<td><strong>90</strong></td>
<td><strong>55</strong></td>
</tr>
</tbody>
</table>

Outage frequency distribution for direct causes is shown in Table 16. From the Table it seems that there is reliability growth in A-link loss, Switch SS7-Process and SCP failure direct causes with the maximum reliability growth in A-link loss.

Also, when we look at total outages it seems that the A-link loss is the major direct cause for SS7 outages. Even though there seems an improvement in A-link loss category it is still a big concern because maximum number of outages in post 9-11 events is due to A-link loss.
Table 16. Direct Cause Frequency

<table>
<thead>
<tr>
<th>Direct Causes</th>
<th>Total Outages</th>
<th>Pre 9-11 Outages</th>
<th>Post 9-11 Outages</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-link loss</td>
<td>111</td>
<td>69</td>
<td>42</td>
</tr>
<tr>
<td>Switch SS7 Process Failure</td>
<td>17</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>SCP Failure</td>
<td>9</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>STP Failure</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Unknown</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>SS7 Network Failure</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>145</strong></td>
<td><strong>90</strong></td>
<td><strong>55</strong></td>
</tr>
</tbody>
</table>

Outage frequency distribution for root causes is shown in Table 17. From the table it seems that there is reliability growth in almost all the root causes except unknown category. Maximum reliability growth is observed in Procedural error.

Also, when we look at total outages it seems that the diversity deficit is the most basic reason for SS7 outages. However, on observing pre 9-11 outages it seems that there is a reliability growth in outages in diversity deficit category. Even though there seems an improvement in diversity deficit category it is still a big concern for industries because maximum number of outages in post 9-11 events are due to diversity deficit.

Table 17. Root Cause Frequency

<table>
<thead>
<tr>
<th>Root Causes</th>
<th>Total Outages</th>
<th>Pre 9-11 Outages</th>
<th>Post 9-11 Outages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedural Error</td>
<td>35</td>
<td>26</td>
<td>9</td>
</tr>
<tr>
<td>Diversity Deficit</td>
<td>69</td>
<td>39</td>
<td>30</td>
</tr>
<tr>
<td>Design Error</td>
<td>24</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>Facility Maintenance</td>
<td>12</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Unknown</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>145</strong></td>
<td><strong>90</strong></td>
<td><strong>55</strong></td>
</tr>
</tbody>
</table>
Overall, the maximum reduction in post 9-11 outages was observed due to-

Trigger Cause: Human Activity (15)

Direct Cause: A-link loss (27)

Root Cause: Procedural Error (17)
Chapter 6

6. Conclusion

6.1 Research question conclusions

Each research question (RQ) is listed below and a short summary presented for each.

6.1.1 RQ 1 on reliability: outage frequency

Are there any differences in SS7 reliability (the failure frequency) before and after 911?

There was reliability growth in all FCC-reportable overall outages and SS7 outages after 9-11. A highly significant Poisson model for all reported outages from 1993-2004 indicates a reduction in outage frequency after 9-11. Similarly Poisson models for SS7 outages indicated reliability growth in SS7 outages after 9-11. All these models indicated constant outages before and after 9-11, with lower outage rates after 9-11.

6.1.2 RQ 2 on SS7 survivability:

6.1.2.1 RQ 2(a) through 2(d)

Is there any difference in the size, blocked calls, duration, or impact of SS7 outages before and after 911?

Survivability growth was indicated by an overall reduction for each of these survivability metrics after 9-11. Also, less variance was observed in all the survivability metrics after 9-11. However, no statistically significant differences in the means were detected. This
means the survivability growth is due primarily to the reduced frequency of outages after 9-11.

6.1.2.2 RQ 2 (e) on outage time of day

Is there any relationship to the time of day at which outage occurs before and after the 911?

No differences were observed in event time of day before and after 9-11. On comparing event time of day it was observed that the difference before and after 9-11 is not significant.

6.1.2.3 RQ 2 (f) on outage day of week

Is there any temporal difference in the outage day of the week before and after the 911?

Most outages occurred weekdays as opposed to weekend. However, little difference was found between the event day of week before and after 9-11. It is noted that the number of outages on the weekend was the same before and after 9-11.
6.1.3 RQ 3 on causality:

**Is there any difference in the causes of SS7 outages before and after 911?**

About -12% difference in procedural error was observed in outage count after 9-11. In addition, about +10% difference was found in outages due to diversity deficit (root) and due to A-link clock failure (direct). However, very few differences were discovered in number of outages due to trigger cause.

While examining causality in the total sample it was found that about 83% of outages were triggered by human activity, direct cause for 77% of outages was A-link loss and the root cause for about 50% of the outages was diversity deficit.

6.1.4 RQ 4 on causality and survivability relationships:

**Are the relationships between causality and survivability the same before and after 911?**

Sixteen (16) instances of ‘Some difference (5-15%)’ were found while analyzing causality and survivability relationship in pre and post 9-11 events as mentioned in section 5.8. Also ten (10) instances of ‘Moderate difference (15-35%)’ and four (4) instances of ‘little differences (<5%)’ were observed in causality-survivability relation between pre and post 9-11 events. Maximum difference (about a +35% difference) was observed in equipment failure trigger cause percent distribution for blocked calls. In addition, about +30% difference in the blocked calls percent distribution was due to
human activity. About a +25% difference was observed in isolated access lines due to lack of power diversity and in blocked calls due to procedural error. It was also determined that major significant differences in causality-survivability relationship are in causal subcategories.

While observing causality and survivability relationships in the total sample, it was determined that most outages were triggered by either human activity, fiber cut or equipment failure. Direct cause for maximum outages was A-link loss, while the prevalent root cause was diversity deficit. A-link loss and diversity deficit each was responsible for about 80% of the outage duration.

6.2 Conclusion for causality analysis by frequency:

Thirty-six unique causality combinations were found which are detailed in Table 14. Out of them maximum reliability growth was observed in human activity – A-link loss – procedural error combination. Maximum reliability deterioration was observed in human activity – A-link loss – diversity deficit combination.

Outages due to human activity (trigger cause), A-link loss (direct cause), and procedural error (root cause) seem to improve most after 9-11 as shown in Tables 15, 16, and 17. The other areas of improvement are equipment failure (trigger), fiber cut (trigger), switch SS7-process failure (direct), diversity deficit (root), and design error (root). However, some increase in post 9-11 events was observed in SS7-network failure (direct) and unknown category.
When the total sample was examined the most frequent combination was *fiber cut--A-link loss--diversity deficit* which was responsible for 25 outages. This was followed by 23 outages due to the *human activity--A-link loss--procedural error* combination. While analyzing individual categories it was determined that most outages were triggered by human activity (55). Direct cause for most of the outages was A-link loss (111) and the root cause was diversity deficit (69).
Chapter 7

7. RESEARCH LIMITATIONS AND FUTURE RESEARCH

A number of research limitations need to be mentioned:

(A) While most of the FCC reports were clear, there were some which contained some ambiguities.

- Some reports listed outage report data as “unknown”. For example in some reports blocked calls were “unknown”. In such cases the value for those metrics was taken as zero.
- Some reports indicated a range for some outage metrics. For example in one of the reports, access lines was listed as “>50,000”. In such cases, lowest value of the range was used in analysis i.e. 50,000 for the above case.
- Events dealing with causality were in written paragraph form and required qualitative assessments on the part of the researcher. In some reports description of the event was unclear. In these instances “unknown” was used for some causal categories.

(B) This research is focused on SS7 outages. The results obtained for SS7 outages may not be applicable to other FCC-reportable outage types.
(C) Only the outages reported to the FCC are part of the analysis. This means that SS7 outages below the FCC reporting thresholds are censored. So conclusions deal with reported SS7 outages meeting the FCC reporting threshold for wireline carriers in the timeframe 1999 to 2004.

In spite of these limitations, this work provided valuable insights into SS7 reliability and survivability, by identifying trigger, direct, and root causality. This information could be used to improve the PSTN.

Lastly, it is noted that new FCC reporting rules went into effect in January 2005. Not only was the reporting threshold lowered, but reporting scope also was expanded to include wireless, cable, and satellite voice communication providers. Future research could include this new data. However, the new regulation no longer makes the data public, severely limiting future empirical research. [35]


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Appendix A

1. Outage 99-2
   1. Vehicle accident severed fiber cable
   2. Both A-links in this cable
   3. DACS failed to route primary A-links to protection backup links
   4. Local switch isolated from SS7 network

   Trigger Cause: Fiber cut (FC)
   Direct Cause: A-Links severed (AL-DL)
   Root Cause: DACS not properly maintained (FACM)

2. Outage 99-3
   1. Technician dropped screw driver on live circuit breaker while replacing it
   2. Loss of power to A-links
   3. A-links lost
   4. Local switch isolated from SS7 network

   Trigger Cause: Human activity (HUM)
   Direct Cause: A-Links lost (AL-DL)
   Root Cause: Lack of power diversity to A-links (DD-PWR)

3. Outage 99-11
   1. Hot standby STP A-link interface cards failed
   2. All associated signaling links lost
   3. Ten local switches isolated from SS7 network

   Trigger Cause: Hardware equipment failure (EF-HW)
   Direct Cause: STP failure (STPF)
   Root Cause: Ten local switches connected to only one STP (DD-AL)

4. Outage 99-13
   1. Operator updating SS7 addresses in Lucent 5ESS local switch makes error
   2. SS7 messages misrouted
   3. Local switch (Lucent 5ESS) isolated from SS7 network

   Trigger Cause: Error by translation technician (HUM)
   Direct Cause: Switch SS7 process failure (SS7-PROC)
   Root Cause: Procedural error (PROCED)

5. Outage 99-14
   1. Problems during Lucent 5ESS switch upgrade generated multiple alarms
   2. Attempts to clear alarms resulted in CNI ring failure
   3. A links lost
   4. Local switch (Lucent 5ESS) isolated from SS7 network
Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-IF)
Root Cause: Vendor had poor procedures (PROCED)

6. Outage 99-18
1. Operator entered incorrect routing entries in Nortel DMS-250 switch for SS7 messages
2. Incorrect routing information caused misrouting of SS7 traffic
3. Switch SS7 process failure resulted in tandem switch (Nortel DMS-250) isolation from SS7 network

Trigger Cause: Error by translation technician (HUM)
Direct Cause: Switch SS7 process failure (SS7-PROC)
Root Cause: Procedural error (PROCED)

7. Outage 99-26
1. Installation of software update on Lucent 5ESS switch
2. Error in CNI ring
3. Lost interface to A-links
4. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Software equipment failure (EF-SW)
Direct Cause: A-links lost (AL-IF)
Root Cause: Faulty software design (DSN-SW)

8. Outage 99-28
1. Congestion in SCP due to SS7 traffic
2. SCP unable to process 800 queries from Nortel DMS switch
3. SCP failure
4. 800 service calls from Nortel DMS switch network timing out and failing

Trigger Cause: Overload (OVL)
Direct Cause: SCP failure (SCPF)
Root Cause: Fault in the software caused congestion (DSN-SW)

9. Outage 99-29
1. Congestion in SCP due to SS7 traffic
2. SCP unable to process 800 queries from Nortel DMS switch
3. SCP failure
4. 800 service calls from Nortel DMS switch network timing out and failing

Trigger Cause: Overload (OVL)
Direct Cause: SCP failure (SCPF)
Root Cause: Fault in the software caused congestion (DSN-SW)
10. Outage 99-34
   1. Digital cross-connect equipment removed during maintenance activity
   2. Disconnected A-links from local switch
   3. Three local switches isolated from SS7 network

   Trigger Cause: Error by technician (HUM)
   Direct Cause: A-links lost (AL-DACS)
   Root Cause: Procedural (PROCED)

11. Outage 99-35
   1. Digging activity unrelated to carrier severed fiber cable
   2. Both A-links in this cable severed
   3. Tandem switch isolated from SS7 network

   Trigger Cause: Fiber cut (FC)
   Direct Cause: A-links severed (AL-DL)
   Root Cause: Lack of A-links diversity (DD-AL)

12. Outage 99-40
   1. Forest fire burned fiber cables
   2. Both A-links in burned cables, however route diversified backup available
   3. A-links switched to backup and primary cable spliced incorrectly
   4. A-links switched to primary misrouted
   5. Local switch isolated from SS7 network

   Trigger Cause: Fiber cut (FC)
   Direct Cause: A-links lost (AL-DL)
   Root Cause: Technicians’ inability to identify the correct fiber and splice it (PROCED).

13. Outage 99-42
   1. While installing new circuit boards in Nortel DMS switch, technician inserted wrong board
   2. A-links lost
   3. Switch (Nortel DMS) isolated from SS7 network

   Trigger Cause: Error by installation technician (HUM)
   Direct Cause: A-links lost (AL-IF)
   Root Cause: Procedural (PROCED)

14. Outage 99-45
   1. Failed circuit boards in OC-12 multiplexer
   2. OC-12 transmission system lost
   3. Both A-links multiplexed on OC-12
   4. Switch isolated from SS7 network

   Trigger Cause: Equipment failure (EF-HW)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-links diversity (DD-AL)

15. Outage 99-55
   1. Software bug in OC-48 transmission system
   2. OC-48 transmission system lost
   3. Numerous D-links in OC-48
   4. Local STPs isolated from Gateway STP pairs
   5. InterLATA calls could not be placed
   6. Local switches (FT2000) isolated from SS7 network

Trigger Cause: Software equipment failure (EF-SW)
Direct Cause: D-links lost (SS7-N)
Root Cause: Lack of diversity in D-links (DD-DL)

16. Outage 99-56
   1. A contractor severed fiber while digging
   2. High speed digital link (T4X) lost
   3. Both A-links multiplexed onto T4X
   4. Local switch isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of A-links diversity (DD-AL)

17. Outage 99-57
   1. Routine replacement of faulty circuit card in Lucent 5ESS switch
   2. Technician followed procedures and CNI ring failed
   3. Lost interface to A-links
   4. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Software equipment failure (EF-SW)
Direct Cause: A-links lost (AL-IF)
Root Cause: Switch vendor design error (DSN-SW)

18. Outage 99-66
   1. CNI ring node conversion in Lucent 5ESS switch
   2. Component associated with CNI failed
   3. Lost interface to A-links
   4. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-IF)
Root Cause: Unknown (UNK)
19. Outage 99-67
   1. Technician forgot to install cables between processor and CNI ring during processor conversion
   2. CNI ring failed during conversion when old processor removed
   3. Lost interface to A-links
   4. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-IF)
Root Cause: Engineering left cable connection out of technician instructions (DSN-HW)

20. Outage 99-75
   1. Construction crew severed fiber cable while digging
   2. High speed digital link (T4X) lost
   3. Both A-links multiplexed onto T4X
   4. Eight local switches isolated from SS7 network

Trigger Cause: Two Fiber cables cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of physical diversity (DD-AL)
Secondary Root Cause: Carrier construction crew did not follow the correct procedure for locating cable before digging (PROCED)

21. Outage 99-80
   1. Fiber cable severed while digging along cable route
   2. Both A-links in this cable
   3. Twenty one local switches isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

22. Outage 99-83
   1. Software error in the SCP
   2. SCP unable to process certain queries
   3. Congestion in SCP (SCP buffer overloaded)
   4. SCP failure

Trigger Cause: Software equipment failure (EF-SW)
Direct Cause: SCP failure (SCPF)
Root Cause: Faulty software design (DSN-SW)

23. Outage 99-88
   1. Technician was disconnecting SS7 trunk group during a maintenance activity
   2. Erroneous deletion of additional routing information
3. Switch SS7 process failure resulted in five local switches (Lucent 5ESS) being isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: Switch SS7 process failure (SS7-PROC)
Root Cause: Procedural (PROCED)

24. Outage 99-99
1. Technician working on a problem causing switch alarm
2. Erroneous deletion of translations for cluster routing (“Cluster routing is a technique used to route traffic by multiple trunk groups to the same destination”)
3. Switch SS7 process failure resulted in local switch (Lucent 5ESS) isolation from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: Switch SS7 process failure (SS7-PROC)
Root Cause: Procedural (PROCED)

25. Outage 99-103
1. Extensive heat caused the power board in multiplexer to fail
2. Both A-links in multiplexer
3. Local switch isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-MUX)
Root Cause: Lack of A-link diversity (DD-AL)

26. Outage 99-106
1. Voltage spike shut down rectifiers
2. Facility DC voltage low
3. Timing clock equipment failed
4. A-Links lost
5. Local switch isolated from SS7 network

Trigger Cause: Faulty power supply (PWR)
Direct Cause: A-link lost (AL-DL)
Root Cause: Alarms not working (FACM)

27. Outage 99-112
1. Lucent 5-ESS SS7 switch process not working
2. Technician forced to backup control unit
3. CNI ring re-initialized but did not operate properly
4. Lost interface to A-links
5. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Technician misdiagnosed the problem (HUM)
Direct Cause: A-links lost (AL-IF)
Root Cause: Procedural (PROCED)

28. Outage 99-115
1. Defective hardware in CNI ring node left un-repaired for some unknown time
2. During maintenance routine tried to use defective hardware causing loss of CNI capability to send/receive messages
3. Switch software unable to detect CNI fault, thus switch SS7 signaling impaired
4. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Preventive maintenance activity (HUM)
Direct Cause: A-links lost (AL-IF)
Root Cause: Faulty SS7 switch process bug that did not recognize loss of CNI capability (DSN-SW)

29. Outage 99-121
1. Technician installing additional T1 circuits and requested loop back to test circuit
2. Instead of looping back new circuit, existing T1 in service was looped.
3. Both A-links multiplexed onto T1 that was mistakenly looped back
4. Six local switches isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DL)
Root Cause: Procedural (PROCED)

30. Outage 99-129
1. New Nortel DMS-100 homed to tandem Nortel DMS-200
2. Additional switch increased tandem SS7 message traffic
3. Tandem switch A-link set not enough capacity for new situation as this set was congested
4. Call process interruption in Nortel DMS-200 tandem switch because of SS7 isolation

Trigger Cause: Overload (OVL)
Direct Cause: A-links lost (AL-DL)
Root Cause: Engineering error as another link set should have been added to tandem when Nortel DMS-100 cutover (DSN-HW)

31. Outage 99-174
1. Diverse A-links patched onto same T3 because of transmission failure
2. Loose connection in T3 digital link system
3. Both A-links multiplexed onto T3
4. Local switch isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

32. Outage 99-188
1. SCP software failed
2. SCP unable to process certain queries
3. Congestion in SCP
4. SCP failure
5. Twenty local switches isolated from SS7 network

Trigger Cause: Software equipment failure (EF-SW)
Direct Cause: SCP failure (SCPF)
Root Cause: Faulty software design (DSN-SW)

33. Outage 99-196
1. Operator severed fiber cable while digging
2. Both A-links in this cable
3. Ten local switches isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Physical diversity of A-links was there but not utilized (DD-AL)

34. Outage 99-199
1. While installing ring node equipment in the Lucent 5ESS switch, CNI primary path failed because of improper documentation
2. Then technician dropped screw onto ring power source, causing power loss to the CNI backup path
3. CNI failure
4. Loss of switch interface to A-links
5. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-IF)
Root Cause: Procedural (PROCED)

35. Outage 99-202
1. Technician mistakenly removed duplex A-links
2. Switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

36. Outage 99-207
1. Contractor severed fiber cable
2. Both A-links in this cable
3. Local switch isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

37. Outage 99-211
   1. Fiber cut by a farm employee
   2. Both A-links in this cable
   3. Local switch isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

38. Outage 99-216
   1. Technician installing new SONET multiplexer accidentally shorted CO battery to D4 channel banks
   2. Power to two D4 channel banks lost
   3. One A-links in each channel bank
   4. Local switch (DMS-100) switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-MUX)
Root Cause: Power diversity deficit (DD-PWR)

39. Outage 99-221
   1. During switch upgrade technician removed DC fuses from data facility cabinet
   2. A-links lost as they were in the cabinet
   3. Local switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DL)
Root Cause: Procedural (PROCED)

40. Outage 99-222
   1. OSS router started sending erroneous messages to the switch
   2. Switch processor control units processed erroneous messages, and failed
   3. SS7 process failure
   4. Local switch (Lucent 5ESS switch) isolated from SS7 network

Trigger Cause: Faulty OSS router (EF-SW)
Direct Cause: Switch SS7 process failure (SS7-PROC)
Root Cause: Router not properly maintained (DSN-SW)
41. Outage 99-224
   1. Water leakage from the cooling system above DACS equipment
   2. DACS failed
   3. DS3 (256) circuit going through DACS failed
   4. Lost C-links

   Trigger Cause: Environmental Factor (ENV)
   Direct Cause: C-links lost (AL-DACS)
   Root Cause: Lack of C-link diversity (DD-CL)

42. Outage 00-3
   1. Undersized fuses placed in A & B DC power circuits to OC-48 multiplexer
   2. Fuses blew causing loss of power to the multiplexer
   3. A-links riding same OC-48
   4. Local switch SS7 isolated

   Trigger Cause: Technician placed wrong size fuses (HUM)
   Direct Cause: A-links lost (AL-MUX)
   Root Cause: Procedural (PROCED)

43. Outage 00-34
   1. During switch upgrade required software feature failed to enable
   2. Switch SS7 process that was to manage A-link utilization during upgrade failure
   3. Local (Lucent 5ESS) switch isolated from SS7 network

   Trigger Cause: Software equipment failure (EF-SW)
   Direct Cause: Switch SS7 process failure (SS7-PROC)
   Root Cause: Faulty software design (DSN-SW)

44. Outage 00-35
   1. Trunk Delete orders issued then cancelled
   2. Cancellation order ignored and trunk translations deleted
   3. A-links lost due to translation error
   4. Tandem switch (Lucent 4ESS) SS7 isolated

   Trigger Cause: Human activity (HUM)
   Direct Cause: A-links lost (AL-DL)
   Root Cause: Procedural (PROCED)

45. Outage 00-36
   1. During switch upgrade required software feature failed to enable
   2. Switch SS7 process that was to manage A-link utilization during upgrade failure
   3. Local switch (Lucent 5ESS) isolated from SS7 network
Trigger Cause: Software equipment failure (EF-SW)
Direct Cause: Switch SS7 process failure (SS7-PROC)
Root Cause: Faulty software design (DSN-SW)

46. Outage 00-53
1. Fiber cable severed by a contractor
2. Both A-links in this cable
3. Local switches isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

47. Outage 00-75
1. Hot standby digital transmission system experienced power anomaly
2. Digital transmission terminal (Secure 7) failed
3. Both A-links in failed transmission system
4. Local switches isolated from SS7 network

Trigger Cause: Power anomaly (PWR)
Direct Cause: A-links lost (AL-DL)
Root Cause: Equipment diversity deficit (DD-SPF)

48. Outage 00-77
1. Contractor severed fiber cable
2. Fiber ring cannot switch to protect path because of defective optical transmit card
3. Dual A-links failure
4. Local switch isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

49. Outage 00-80
1. SCP lost capability to send messages to 800 database
2. SCP unable to access 800 database
3. Congestion in SCP
4. SCP failed

Trigger Cause: Software equipment failure (EF-SW)
Direct Cause: SCP failure (SCPF)
Root Cause: Faulty software design (DSN-SW)

50. Outage 00-82
1. Constructor severed a fiber cable
2. Both A-links in this cable
3. Local switch isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

51. Outage 00-86
   1. Contractor severed fiber cables
   2. Both A-links in this cable
   3. Local switch isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

52. Outage 00-92
   1. Vendor working with timing leads
   2. Accidentally blew fuse to both external timing clock power feeds
   3. CO lost timing clock
   4. A-links receiving power from the same clock failed
   5. Local switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Power diversity deficit (DD-PWR)

53. Outage 00-98
   1. Fiber optic cable severed by road grader
   2. Both A-links in this cable
   3. Three local switches (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

54. Outage 00-101
   1. Primary timing card failed
   2. Digital clock distributor unable to switch the timing card to protection
   3. A-links receiving timing from the same clock failed
   4. Local switch isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Equipment diversity deficit (DD-SPF)
55. Outage 00-103
1. Timing clock failed during upgrade
2. A-links receive external timing from this clock
3. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Replacement of timing system (HUM)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Correct procedure not followed while upgrading timing clock (PROCED)

56. Outage 00-104
1. While implementing manual data correction in SCP, correction was typed wrongly
2. Database record corrupted
3. SCP memory database reloaded
4. SCP failure

Trigger Cause: Human activity (HUM)
Direct Cause: SCP failure (SCPF)
Root Cause: Procedural (PROCED)

57. Outage 00-107
1. Technician performing conversion on a switch
2. Mistakenly failed to recheck software configuration
3. Switch SS7 process failure
4. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: Switch SS7 process failure (SS7-PROC)
Root Cause: Procedural (PROCED)

58. Outage 00-111
1. Vendor generated a surge condition
2. Power distribution panel failed
3. Relay racks failed
4. A-links failed

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-MUX)
Root Cause: Procedural (PROCED)

59. Outage 00-113
1. Noisy power supply
2. Fiber system switched to protect side which was inoperable
3. Alarm not generated because of faulty alarm system
4. Both A-links down because both links through same transmission system
5. Local switch isolated from SS7 network
Trigger Cause: Power supply (PWR)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)
Secondary Root Cause: Faulty alarm system (FACM)

60. Outage 00-116
1. While installing new multiplexer, technician mistakenly inserted disabled pins in timing clock
2. Hot standby external timing clock failed
3. A-links lost
4. Tandem switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-link lost (AL-CLK)
Root Cause: Procedural (PROCED)

61. Outage 00-118
1. Technician working on simplex A-link failure found faulty circuit boards in D4 channel bank
2. Circuit boards configured links for 64 Kbps instead of 56 Kbps on replacement
3. Duplex A-links failure
4. Local switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-MUX)
Root Cause: Procedural (PROCED)

62. Outage 00-121
1. Technician accidentally grounded the battery leads
2. Fuse in ‘Battery distribution fuse board’ blew
3. Timing clock lost power
4. A-links failed
5. Local switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Power diversity deficit in timing clock (DD-PWR)
Secondary Root Cause: Procedural (PROCED)

63. Outage 00-122
1. Fiber cable severed by paving company
2. Fiber ring went into simplex mode
3. Microwave radio trouble caused the failure of protection link
4. Both A-links lost
5. Local switch isolated from SS7 network
Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Unknown (UNK)

64. Outage 00-136
   1. Technician accidentally severed fiber cables
   2. Both A-links in this cable
   3. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links severed (AL-DL)
Root Cause: Procedural (PROCED)

65. Outage 00-148
   1. LNP message overload between CNI and SCP processor
   2. Communication failure between CNI and SCP processor
   3. Lost interface to A-links
   4. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Overload (OVL)
Direct Cause: A-links lost (AL-DL)
Root Cause: Hardware design error (DSN-HW)

66. Outage 00-150
   1. Routing translations for E-911 functions were deleted from switch by technician
   2. SS7 process failure
   3. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: Switch SS7 process failure (SS7-PROC)
Root Cause: Procedural (PROCED)

67. Outage 00-151
   1. Circuit board in the attached switch processor interface fails
   2. Switch SS7 process failed
   3. Local switch (Lucent 1AES) isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: Switch SS7 process failure (SS7-PROC)
Root Cause: Hardware equipments not properly maintained (FACM)

68. Outage 00-154
   1. Contractor severed fiber cable
   2. Fiber ring unable to switch to protect side because of defective transmitter card
   3. A-links lost
4. Local switch isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Hardware equipments not properly maintained (FACM)

69. Outage 00-156
1. Circuit board in the switch processor interface failed
2. Switch SS7 process went down
3. Local switch (Lucent 1AESS) isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: Switch SS7 process failure (SS7-PROC)
Root Cause: Hardware equipments not properly maintained (FACM)

70. Outage 00-161
1. Construction crew severed fiber cable
2. Both A-links in this cable
3. Local switch isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

71. Outage 00-162
1. Technician accidentally broke some pins on timing distribution shelf
2. Loss of power to timing clock
3. A-links lost
4. Local switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Procedural (PROCED)

72. Outage 00-163
1. Water entered the cable through an open splice
2. Fuse blew causing loss of power to timing clock
3. Local and Tandem switch (Nortel DMS-100/200 switch) isolated from SS7 network

Trigger Cause: Environmental Factor (ENV)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Power diversity deficit in timing clock (DD-PWR)

73. Outage 00-165
1. Power anomaly caused loss of power to timing clock
2. External timing clock failed
3. A-links lost
4. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Power supply (PWR)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Power diversity deficit in timing clock (DD-PWR)

74. Outage 00-166
   1. Receive fiber connection in multiplexer became loose
   2. Loss of input signal to multiplexer
   3. Multiplexer not able to switch to protect side
   4. Both A-links going through multiplexer
   5. Two local switches SS7 isolated

Trigger Cause: Unknown (UNK)
Direct Cause: A-links lost (AL-MUX)
Root Cause: Lack of A-link diversity (DD-AL)

75. Outage 00-167
   1. Technician mistakenly took both A-links offline
   2. Local switch (Nortel DMS-100) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DL)
Root Cause: Procedural (PROCED)

76. Outage 00-168
   1. High speed optical card being replaced in Secure 7 OC-3 transmission system
   2. Card subsequently failed
   3. OC-3 carrying A-links for 17 COs
   4. Seventeen local switches isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-DL)
Root Cause: Procedural (PROCED)

77. Outage 00-173
   1. Receive fiber connection in multiplexer became loose
   2. Loss of input signal to multiplexer
   3. Multiplexer not able to switch to protect side
   4. Both A-links going through multiplexer
   5. Local switch isolated from SS7 network

Trigger Cause: Unknown (UNK)
Direct Cause: A-links lost (AL-MUX)
Root Cause: Lack of A-link diversity (DD-AL)
78. Outage 00-174
   1. Technician working on CNI ring accidentally removed A-links from Lucent
      5ESS tandem switch
   2. No verification performed to see that correct A-links were in service before
      leaving
   3. Tandem switch (Lucent ISDN/E911 5ESS) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-IF)
Root Cause: Incomplete Documentation (PROCED)

79. Outage 00-180
   1. While placing a new drainage system, fiber cable severed
   2. OC-48 transmission system and High speed digital link (T4X) used cable
   3. A-links all in T4X
   4. Local switch and a PSAP isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

80. Outage 00-182
   1. Circuit board in external timing clock failed
   2. External timing clock failed
   3. A-links lost
   4. Local switch (Lucent 1AESS) isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost as both links on same timing source (AL-CLK)
Root Cause: Equipment diversity deficit (DD-SPF)

81. Outage 00-185
   1. Contractor moving timing leads from one Stratum clock to another
   2. New timing source not ready for service
   3. Timing to A-links lost
   4. Local switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Procedural (PROCED)

82. Outage 00-190
   1. Switch dual attached processor interface failed
2. Processor unable to communicate with switch
3. Local switch (Lucent 1AESS) isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: Switch SS7 process failure (SS7-PROC)
Root Cause: Hardware equipment not properly maintained (FACM)

83. Outage 00-192
1. Power card failure on STP
2. Backup power card on STP also failed
3. STP failure
4. SS7 traffic routed by switch to alternate STP
5. A-link to alternate STP could not handle full load
6. Switch isolated from SS7 network

Trigger Cause: STP power failure (EF-HW)
Direct Cause: Link congestion made A-link unusable (AL-DL)
Root Cause: A-link under capacity required to handle entire load (DSN-HW)

84. Outage 00-193
1. Technician accidentally removed SS7 node addressing from the switch
2. MSC wireless switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: Switch SS7 process failure (SS7-PROC)
Root Cause: Procedural (PROCED)

85. Outage 00-198
1. Fiber severed by a roadwork contractor
2. Both A-links in this cable
3. Local switch isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

86. Outage 00-209
1. Exposed metallic cable dropped by a worker hit exposed pins on external timing clock
2. Power feed fuses in ‘Battery distribution fuse bay’ blew
3. Failure of external timing clock
4. A-links receiving timing from the same clock failed
5. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Equipment diversity deficit (DD-SPF)
Secondary Root Cause: No physical protection on timing clock leads (FACM)

87. Outage 00-218
1. Technician moving cables from one fused DC circuit to another
2. Bolt made contact with metal bracket
3. Power panel circuit breaker that serves DACS tripped
4. Circuit breaker served A and B side power to all DACS
5. A-links failed when circuit breaker not reset
6. Local switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DACS)
Root Cause: Faulty power diversification (DD-PWR)
Secondary Root Causes: Technicians evidently left without resetting circuit breaker or checking with the NOC for alarm conditions (PROCED).

88. Outage 00-222
1. Nortel DMS-100 switch internal clock cards failed
2. Switch lost A-links, restarted to end isolation
3. Replaced internal clock cards in switch
4. Restarted but failed to reacquire internal clock before 30 minutes passed
5. Local switch (Nortel DMS-100) isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-IF)
Root Cause: Faulty software design (DSN-SW)

89. Outage 00-223
1. A-links failed
2. Faulty circuit boards in switch replaced
3. Software upgrades did not load onto replaced card
4. Both A-link out
5. Local switch isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-IF)
Root Cause: Switch not updated with latest software upgrade (FACM)

90. Outage 00-225
1. Water main broke flooding the water to basement
2. Power plant rectifiers were in basement and shorted
3. Low voltage condition when batteries started to deplete
4. All CO equipment failed
5. Two other CO A-links ran through the affected CO
6. Two local switches isolated from SS7 network
Trigger Cause: Environmental Factor (ENV)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)
Secondary Root Cause: Hardware design error as power plant in basement (DSN-HW)

91. Outage 03-4
   1. T1 transmission equipment failed
   2. Both A-links multiplexed onto T1
   3. Local switch isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

92. Outage 03-6
   1. Technicians updating SCP for a VPN project deleted a default route to a tandem switch for non VPN calls
   2. Millions of VPN call requests could not find default route to tandem for off net calls generating massive query traffic to SCP
   3. Virtual private network off net calls blocked

Trigger Cause: Human activity (HUM)
Direct Cause: SCP routing error impaired (SCPF)
Root Cause: Procedural (PROCED)

93. Outage 03-7
   1. Digital clock distribution timing card failed and switched to alternate
   2. Technician arrived and switched it back to the primary faulty card
   3. A-links lost external clock

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Lack of A-link diversity (DD-AL)

94. Outage 03-8
   1. Fire burned fiber cables
   2. One A-link in burned cables
   3. A-link to alternate STP could not handle full load
   4. Local switch isolated from SS7 network

Trigger Cause: A-link severed by fire (FC)
Direct Cause: Link congestion made A-link unusable (AL-DL)
Root Cause: A-link under capacity required to handle entire load (DSN-HW)

95. Outage 03-10
1. Contractor dropped metal strap on the live DC distribution circuitry
2. Fuse blow
3. A-links lost
4. Local switches (Lucent 5ESS & Nortel DMS-100) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DL)
Root Cause: Power diversity deficit (DD-PWR)

96. Outage 03-11
1. DC circuit breaker tripped
2. Circuit breaker provided A & B power to redundant timing clock
3. A-links lost
4. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Loss of DC power because of circuit breaker tripped (PWR)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Power diversity deficit in timing card (DD-PWR)

97. Outage 03-13
1. Fiber cable severed during a sewer repair
2. Both A-links in this cable
3. Local switch isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links severed (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

98. Outage 03-21
1. Transient fault caused false system initialization message in the switch
2. Switch lost connectivity to A-links
3. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Switch software anomaly (EF-SW)
Direct Cause: A-links lost (AL-IF)
Root Cause: Faulty software design (DSN-SW)
Secondary Root Cause: Failure to first work on switch (PROCED)

99. Outage 03-23
1. Technician accidentally shorted main DC power source from panel
2. Voltage surge caused CNI to go down
3. Lost interface to A-links
4. Tandem switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-IF)
Root Cause: Procedural (PROCED)

100. Outage 03-24
1. While removing equipment a relay rack was powered down
2. Power circuit also provided power to both sides of redundant timing clock
3. A-links lost
4. Local switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Power diversity deficit in timing clock (DD-PWR)

101. Outage 03-33
1. Switch sporadically lost use of A-links
2. Switch started recovery sequence and caused congestion in mated A-links
3. Both A-links unusable
4. Tandem switch isolated from SS7 network

Trigger Cause: Unknown (UNK)
Direct Cause: A-links lost (AL-DL)
Root Cause: Unknown (UNK)

102. Outage 03-34
1. DACS failed
2. A-links lost
3. Two local switches isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-DACS)
Root Cause: Equipment diversity deficit (DD-SPF)

103. Outage 03-37
1. Technician installed data cables to DACS
2. DACS misrouted high speed A-links
3. DACS serviced eight other switch A-links that went through this facility
4. Local switches isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DACS)
Root Cause: Lack of A-link diversity (DD-AL)

104. Outage 03-39
1. DC power cable and fuse upgrade
2. Technician miscalculated the DC load
3. Fuse blows
4. Power outage to OC-12/OC-48 transmission systems
5. A-links lost
6. Sixteen local switches, one tandem switch, and twenty-three E911 PSAP isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DL)
Root Cause: Power diversity deficit (DD-PWR)

105. Outage 03-41
   1. Construction vehicle severed fiber cable
   2. D-links pairs between other carrier STPs failed
   3. SS7 isolation

Trigger Cause: Fiber cut (FC)
Direct Cause: D-links lost (SS7-N)
Root Cause: A-link diversity deficit (DD-AL)

106. Outage 03-42
   1. Power transformer failed due to the vegetation grown outside building
   2. Generator failed
   3. Low facility voltage caused multiple equipments to fail
   4. Local switch CNI failed and lost interface to A-links
   5. Local switches isolated from SS7 network

Trigger Cause: Environmental Factor (ENV)
Direct Cause: A-links lost (AL-IF)
Root Cause: Lack of A-link diversity (DD-AL)

107. Outage 03-43
   1. Technician performing maintenance on OC-48 SONET ring
   2. Technician replaced a faulty transmitter card
   3. Technician did not recognize alarm to show both sides of ring down
   4. Both A-links used ring so A-links out
   5. Local switches isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-RING)
Root Cause: Lack of A-link diversity (DD-AL)

108. Outage 03-52
   1. Loss of connectivity between XA core and universal signaling point
   2. Loss of SS7 signaling

Trigger Cause: Unknown (UNK)
Direct Cause: SS7 Network (SS7-N)
Root Cause: Unknown (UNK)

109. Outage 03-68
   1. Tree fell
   2. Fiber cable severed
   3. Both A-links in this cable
   4. Local switch isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

110. Outage 03-72
   1. Landscaping company placing a conduit severed the fiber cable
   2. Both A-links in this cable
   3. Three local switches isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

111. Outage 03-73
   1. Storm and lightning struck microwave tower
   2. Electromagnetic induction spikes caused switch processor to fail
   3. A-links failure
   4. Local switch (Lucent 1AESS) switch isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: Could be Switch SS7 process or A-Link interface (UNK)
Root Cause: Inadequate grounding design strategy (DSN-HW)

112. Outage 03-75
   1. Vandalism of fiber cable
   2. A-links in this cable
   3. Two switches isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

113. Outage 03-89
   1. Technician was taking SCP links out of service
   2. Accidentally removed active links from database
   3. A-links lost
   4. Local switch (Nortel DMS-100) isolated from SS7 network
Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DL)
Root Cause: Procedural (PROCED)

114. Outage 03-97
   1. Technician removed fuse from CNI ring
   2. CNI ring failed
   3. Lost interface to A-links
   4. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-IF)
Root Cause: Procedural (PROCED)

115. Outage 03-105
   1. Redundant transmission system fails as primary side had failed transmitter and
      protect side had faulty power supply card
   2. Both A-links used transmission system
   3. Both A-links lost
   4. Thirteen local switches became isolated from SS7 network

Trigger Cause: Equipment failure (EF-HW)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

116. Outage 03-107
   1. Software fault in local switch (Siemens EWSD)
   2. Technician actions in trying to recover switch resulted in loss of SS7 process
   3. Local switch lost SS7 capability

Trigger Cause: Software equipment failure in local switch (EF-SW)
Direct Cause: SS7 capability lost (SS7-PROC)
Root Cause: Faulty software design (DSN-SW)

117. Outage 03-110
   1. Technician upgraded the external timing clock erroneously
   2. External timing clock failed
   3. A-links lost
   4. Local switch (Nortel DMS-100/200) switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Procedural (PROCED)

118. Outage 03-113
   1. External timing card failed
2. System unable to switch to protection because of another faulty card in the protection path
3. All A-links received timing from active side
4. Local switch isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Equipment diversity deficit (DD-SPF)

119. Outage 03-114
1. Technician mistakenly deleted SS7 addressing table in gateway STP
2. Gateway STPs rejected all other carriers’ messages
3. ILEC rejected call requests from Wireless carrier

Trigger Cause: Human activity (HUM)
Direct Cause: STP failure (STPF)
Root Cause: Procedural (PROCED)

120. Outage 03-119
1. Earthquake
2. Heavy call volume resulted in the failure of CNI
3. Lost interface to A-links
4. Tandem switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Heavy call volume due earthquake (OVL)
Direct Cause: A-links lost (AL-IF)
Root Cause: Unknown (UNK)

121. Outage 03-120
1. Defective timing card
2. No protection card available
3. External timing clock failed
4. A-links receiving timing from the same clock failed
5. Local switch (Nortel DMS-100) isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Equipment diversity deficit (DD-SPF)

122. Outage 03-121
1. Fiber between STP and SSP damaged by a road crew
2. Both A-links in this cable
3. STP isolated

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

123. 04-4
   1. Technician shorted DC power feed
   2. Fuse blew
   3. External timing clock failed
   4. A-links lost
   5. Local switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Power diversity deficit (DD-PWR)

124. 04-6
   1. HVAC heating plant failed
   2. CO temperature dropped below freezing
   3. Water pipe burst
   4. External timing clock failed
   5. A-links lost
   6. Local switch isolated from SS7 network

Trigger Cause: Environmental (ENV)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Improper maintenance of HVAC (FACM)

125. 04-7
   1. SS7 addressing were removed from remote STP pairs
   2. D-links lost
   3. Remote STP pairs unable to communicate

Trigger Cause: Operator removed the SS7 routing entries (HUM)
Direct Cause: D-links lost (SS7-N)
Root Cause: Procedural (PROCED)

126. 04-10
   1. Alarm unit card replaced
   2. New card did not get the correct cross connect information
   3. A-links lost
   4. Two local switches (host offices) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

127. Outage 03-11
   1. Technician accidentally removed fuses from A-link modems
2. Four A-links lost
3. Local switch (General DataComm 500) isolated from SS7 network
Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DL)
Root Cause: Power diversity deficit (DD-PWR)

128. Outage 03-17
1. Switch A-link interface corrupted
2. A-links lost
3. Local switch isolated from SS7 network

Trigger Cause: Software equipment failure (EF-SW)
Direct Cause: A-links lost (AL-IF)
Root Cause: Lack of A-link diversity (DD-AL)

129. Outage 04-21
1. Buffer overflow in USP backplane due to traffic increase
2. USP removed A-links to clear congestion
3. Switches were isolated from USP

Trigger Cause: Overload (OVL)
Direct Cause: A-links lost (AL-DL)
Root Cause: Failure to put latest software upgrade onto USP (FACM)

130. Outage 04-24
1. Buffer overflow in USP backplane due to traffic increase
2. USP removed A-links to clear congestion
3. Switches were isolated from USP

Trigger Cause: Overload (OVL)
Direct Cause: A-links lost (AL-DL)
Root Cause: Failure to put latest software upgrade onto USP (FACM)

131. Outage 04-28
1. Technician accidentally severed timing leads
2. External timing clock failed
3. A-links lost
4. Switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Procedural (PROCED)

132. Outage 04-29
1. Primary timing card supplying timing to A-links failed
2. Unable to switch to alternate source as the alternate card was out of service
3. External timing clock failed
4. A-links lost
5. Local switch (Lucent 5ESS) isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Timing clock not properly maintained (FACM)

133. Outage 04-31
   1. Constructor severed fiber cable
   2. Both A-links on this cable
   3. Local switches isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links lost (AL-DL)
Root Cause: Lack of A-link diversity (DD-AL)

134. Outage 04-33
   1. STP broadcast erroneous messages
   2. Lucent 4ESS switches processed erroneous messages and blocked traffic from
      a Nortel DMS switch
   3. Tandem switch (Nortel DMS-250) could not process calls through Lucent
      4ESS switch

Trigger Cause: Unknown why STP broadcast (UNK)
Direct Cause: 4ESS SS7 processes reacted to erroneous messages (SS7-PROC)
Root Cause: Software design error (DSN-SW)

135. Outage 04-39
   1. Heavy rain, wind and hail caused water leakage in CO
   2. Water damaged switch equipment which provided SS7 process capability
   3. Tandem switch (Nortel DMS-200) isolated from SS7 network

Trigger Cause: Environmental error (ENV)
Direct Cause: SS7 process capability lost (SS7-PROC)
Root Cause: Roof damage undiscovered (FACM)

136. Outage 04-43
   1. Contractor mistakenly removed fuses that took transmission system down
   2. Transmission system carried both A-links
   3. A-links lost
   4. Local switch (GTD-5) isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: A-links lost (AL-DL)
Root Cause: A-links diversity deficit (DD-AL)
137. Outage 04-46
   1. Fireworks burned fiber cable carrying numerous SONET rings
   2. SONET ring deployed in a “folded” configuration wherein a cut failed active
      and protect sides
   3. Many A-links in the burned cable
   4. Ten local switches isolated from SS7 network

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links lost because folded ring installation (AL-RING)
Root Cause: A-links diversity deficit (DD-AL)

138. Outage 04-51
   1. Fiber cut severed SONET rings installed on same path
   2. Another cut caused SONET rings to fail
   3. A-link lost
   4. Two local switches SS7 isolated

Trigger Cause: Fiber cut (FC)
Direct Cause: A-links lost (AL-RING)
Root Cause: A-links not on physically diverse systems (DD-AL)

139. Outage 04-58
   1. Timing card failed
   2. External timing clock lost
   3. A-links receiving timing from the same clock failed
   4. Local switch isolated from SS7 network

Trigger Cause: Hardware equipment failure (EF-HW)
Direct Cause: A-links lost (AL-CLK)
Root Cause: Equipment diversity deficit (DD-SPF)

140. Outage 04-92
   1. Technician accidentally deleted SS7 addresses in local switch
   2. SS7 routing failed
   3. Local switch isolated from SS7 network

Trigger Cause: Human activity (HUM)
Direct Cause: SS7 process failure (SS7-PROC)
Root Cause: Procedural (PROCED)

141. Outage 04-100
   1. Road grader damaged fiber cable
   2. Both A-links in this cable
   3. Local switch isolated from SS7 network
Trigger Cause: Fiber cut (FC)  
Direct Cause: A-links lost (AL-DL)  
Root Cause: Lack of A-links diversity (DD-AL)

142. Outage 04-104  
1. Software error in SCP  
2. SCP component failed to re-initialize  
3. SCP failed  
4. Tandem switch (Nortel DMS-250) isolated from SS7 network  

Trigger Cause: Software equipment failure (EF-SW)  
Direct Cause: SCP failure (SCPF)  
Root Cause: Software design error (DSN-SW)

143. Outage 04-105  
1. Software error in SCP  
2. SCP component failed to re-initialize  
3. SCP failed  
4. Tandem switch (Nortel DMS-250) isolated from SS7 network  

Trigger Cause: Software equipment failure (EF-SW)  
Direct Cause: SCP failure (SCPF)  
Root Cause: Software design error (DSN-SW)

144. Outage 04-106  
1. Technician improperly installed connector on DS3X digital signal cable  
2. Four A-links lost  
3. Two local switches isolated from SS7 network  

Trigger Cause: Human activity (HUM)  
Direct Cause: A-links lost (AL-DL)  
Root Cause: Lack of A-link diversity (DD-AL)

145. Outage 04-109  
1. Software error in STP  
2. STP failed  
3. Congestion in network  

Trigger Cause: Software equipment failure (EF-SW)  
Direct Cause: STP failure (STPF)  
Root Cause: Software design error (DSN-SW)
Appendix B

OUTAGE COUNT DISTRIBUTION BY CAUSE

Figure B.1 Trigger cause: percent event distribution (pre and post 9-11)

Figure B.2 Sub trigger cause: percent equipment distribution (pre and post 9-11)
Figure B.3 Trigger cause: percent event distribution (pooled)

Figure B.4 Sub trigger cause: percent equipment distribution (pooled)

Figure B.5 Direct cause: percent event distribution (pre and post 9-11)
Figure B.6 Sub direct cause: percent A-link distribution (pre and post 9-11)

Figure B.7 Direct cause: percent event distribution (pooled)

Figure B.8 Sub direct cause: percent A-link distribution (pooled)
Figure B.9 Root cause: percent event distribution (pre and post 9-11)

Figure B.10 Sub root cause: percent diversity distribution (pre and post 9-11)

Figure B.11 Sub root cause: percent design error distribution (pre and post 9-11)
Figure B.12 Root cause: percent event distribution (pooled)

Figure B.13 Sub root cause: percent diversity distribution (pooled)

Figure B.14 Sub root cause: percent design error distribution (pooled)
Appendix C

OUTAGE DURATION DISTRIBUTION BY CAUSE

Figure C.1 Trigger cause: percent duration distribution (pre and post 9-11)

Figure C.2 Sub trigger cause: percent equipment duration distribution (pre and post 9-11)
Figure C.3 Trigger cause: percent duration distribution (pooled)

Figure C.4 Trigger cause: percent duration distribution (pre and post 9-11)

Figure C.5 Direct cause: percent duration distribution (pre and post 9-11)
Figure C.6 Sub direct cause: percent A-link duration distribution (pre and post 9-11)

Figure C.7 Direct cause: percent duration distribution (pooled)

Figure C.8 Sub direct cause: percent A-link duration distribution (pooled)
Figure C.9 Root cause: percent duration distribution (pre and post 9-11)

Figure C.10 Root cause: percent diversity duration distribution (pre and post 9-11)

Figure C.11 Root cause: percent design error duration distribution (pre and post 9-11)
Figure C.12 Root cause: percent duration distribution (pooled)

Figure C.13 Sub root cause: percent diversity duration distribution (pooled)

Figure C.14 Sub root cause: percent design error duration distribution (pooled)
Appendix D

ISOLATED ACCESS LINES DISTRIBUTION BY CAUSE

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**Figure C.1** Trigger cause: percent isolated access lines distribution (pre and post 9-11)

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**Figure C.2** Sub trigger cause: percent equipment isolated access lines distribution (pre and post 9-11)
Figure C.3 Trigger cause: percent isolated access lines distribution (pooled)

Figure C.4 Trigger cause: percent equipment isolated access lines distribution (pooled)

Figure C.5 Direct cause: percent isolated access lines distribution (pre and post 9-11)
Figure C.6 Sub direct cause: percent A-link isolated access lines distribution (pre and post 9-11)

Figure C.7 Direct cause: percent isolated access lines distribution (pooled)

Figure C.8 Sub direct cause: percent A-link isolated access lines distribution (pooled)
Figure C.9 Root cause: percent isolated access lines distribution (pre and post 9-11)

Figure C.10 Root cause: percent diversity isolated access lines distribution (pre and post 9-11)

Figure C.11 Root cause: percent design error isolated access lines distribution (pre and post 9-11)
Figure C.12 Root cause: percent isolated access lines distribution (pooled)

Figure C.13 Sub root cause: percent diversity isolated access lines distribution (pooled)

Figure C.14 Sub root cause: percent design error isolated access lines distribution (pooled)
Appendix E

BLOCKED CALLS DISTRIBUTION BY CAUSE

Figure E.1 Trigger cause: percent blocked calls distribution (pre and post 9-11)

Figure E.2 Sub trigger cause: percent equipment blocked calls distribution (pre and post 9-11)
Figure E.3 Trigger cause: percent blocked calls distribution (pooled)

Figure E.4 Sub trigger cause: percent equipment blocked calls distribution (pooled)

Figure E.5 Direct cause: percent blocked calls distribution (pre and post 9-11)
Figure E.6 Sub direct cause: percent A-link blocked calls distribution (pre and post 9-11)

Figure E.7 Direct cause: percent blocked calls distribution (pooled)

Figure E.8 Sub direct cause: percent A-link blocked calls distribution (pooled)
Figure E.9 Root cause: percent blocked calls distribution (pre and post 9-11)

Figure E.10 Sub root cause: percent diversity blocked calls distribution (pre and post 9-11)

Figure E.11 Sub root cause: percent design error blocked calls distribution (pre and post 9-11)
Figure E.12 Root cause: percent blocked calls distribution (pooled)

Figure E.13 Sub root cause: percent diversity blocked calls distribution (pooled)

Figure E.14 Sub root cause: percent design error blocked calls distribution (pooled)
Appendix F

TOTAL CUSTOMERS AFFECTED DISTRIBUTION BY CAUSE

Figure F.1 Trigger cause: percent total customers affected distribution (pre and post 9-11)


Figure F.2 Sub trigger cause: percent equipment total customers affected distribution (pre and post 9-11)

Figure F.3 Trigger cause: percent total customers affected distribution (pooled)

Figure F.4 Sub trigger cause: percent equipment total customers affected distribution (pooled)

Figure F.5 Direct cause: percent total customers affected distribution (pre and post 9-11)
Figure F.6 Sub direct cause: percent A-link total customers affected distribution (pre and post 9-11)

Figure F.7 Direct cause: percent total customers affected distribution (pooled)

Figure F.8 Sub direct cause: percent A-link total customers affected distribution (pooled)
Figure F.9 Root cause: percent total customers affected distribution (pre and post 9-11)

Figure F.10 Sub root cause: percent diversity total customers affected distribution (pre and post 9-11)

Figure F.11 Sub root cause: percent design error total customers affected distribution (pre and post 9-11)
Figure F.12 Root cause: percent total customers affected distribution (pooled)

Figure F.13 Sub root cause: percent diversity total customers affected distribution (pooled)

Figure F.14 Sub root cause: percent design error total customers affected distribution (pooled)
Appendix G

OUTAGE IMPACT DISTRIBUTION BY CAUSE

Figure G.1 Trigger cause: percent impact distribution (pre and post 9-11)

Figure G.3 Trigger cause: percent impact distribution (pooled)
Figure G.5 Direct cause: percent impact distribution (pre and post 9-11)

Pre: 41.3 M Line-Hrs
Post: 26.4 M Line-Hrs

Figure G.7 Direct cause: percent impact distribution (pooled)

Total: 67.7 M Line-Hrs
Figure G.9 Root cause: percent impact distribution (pre and post 9-11)

Figure G.12 Root cause: percent impact distribution (pooled)
Appendix H

IMPACT SEVERITY DISTRIBUTION BY CAUSE

Figure H.1 Impact category summary

Figure H.2 Trigger cause: percent impact severity distribution (pooled)
Figure H.3 Direct cause: percent impact severity distribution (pooled)

Figure H.4 Root cause: percent impact severity distribution (pooled)
Appendix I

DAY OF WEEK EVENT DISTRIBUTION BY CAUSE

Figure H.1 Trigger cause: percentage difference in events on days of week

Figure H.2 Trigger cause: percent days of week distribution (pooled)
Figure H.3 Direct cause: percentage difference in events on days of week

Figure H.4 Direct cause: percent days of week distribution (pooled)
Figure H.5 Root cause: percentage difference in events on days of week

Figure H.6 Root cause: percent days of week distribution (pooled)
Appendix J
TIME SLOT EVENT DISTRIBUTION BY CAUSE

Figure H.1 Trigger cause: percentage difference in pre and post events by timeslot

Figure H.2 Trigger cause: percent time slot distribution (pooled)
Figure H.3 Direct cause: percentage difference in pre and post events by timeslot

Figure H.4 Direct cause: percent time slot distribution (pooled)
Figure H.5 Root cause: percentage difference in pre and post events by timeslot

Figure H.6 Root cause: percent time slot distribution (pooled)
Appendix K

WEEKLY IMPACT DISTRIBUTION BY CAUSE

Figure K.1 Trigger cause: percent weekly impact distribution (pre 9-11)

Figure K.2 Trigger cause: percent weekly impact distribution (post 9-11)
Figure K.3 Direct cause: percent weekly impact distribution (pre 9-11)

Pre: 41.3 M Line-Hrs

Figure K.4 Direct cause: percent weekly impact distribution (post 9-11)

Post: 26.4 M Line-Hrs
Figure K.5 Root cause: percent weekly impact distribution (pre 9-11)

Figure K.6 Root cause: percent weekly impact distribution (post 9-11)
Appendix L

IMPACT DISTRIBUTION OF TIME SLOT BY CAUSE

Figure L.1 Trigger cause: percent time slot impact distribution (pre 9-11)

Pre: 41.3 M Line-Hrs

Figure L.2 Trigger cause: percent time slot impact distribution (post 9-11)

Post: 26.4 M Line-Hrs
Figure L.3 Direct cause: percent time slot impact distribution (pre 9-11)

Pre: 41.3 M Line-Hrs

Figure L.4 Direct cause: percent time slot impact distribution (post 9-11)

Post: 26.4 M Line-Hrs
Figure L.5 Root cause: percent time slot impact distribution (pre 9-11)

Pre: 41.3 M Line-Hrs

Figure L.6 Root cause: percent time slot impact distribution (post 9-11)

Post: 26.4 M Line-Hrs