corrections and changes was minimal, resulting in an adjustment of two tenths of one percent in the LEC TFP.[137] Thus, the core value of this study remains.

We note that Dr. Christensen was the only party to undertake a productivity study. Moreover, Dr. Christensen is a nationally recognized expert in productivity analysis with a substantial record of original research and publications in journals subject to peer review.[138] Other parties used his study as a starting point from which they then deviated. The simple updating of statistics that Christensen performed is a routine professional practice. In addition, the lack of "purity" cited in the PD would virtually disqualify all empirical studies from use in our proceedings. Data problems are common in all applied research and do not, by themselves, disqualify a study.

We also note that Dr. Christensen lists five other studies of TFP differential of the telecommunications industry. Those studies have results of the TFP differential for the telecommunications industry that range from a low of 1.85% to a high of 2.2%. The study periods for the five other studies are long-term (all examine periods in excess of 25 years).

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[137] Dr. Christensen (for Pacific) Exh. 7, Att., pp. 6-7; 2 Tr. 238.

[138] Ex. 6, App. 4 (Resume).

Dr. Christensen studied the period from 1985 to 1993. While we are not convinced that a point estimate of a 2.1% TFP figure recommended by Dr. Christensen is the single "correct" number, the consistency of this finding with the range of findings cited above causes us to conclude that the "correct" TFP amount lies in a range between 1.8 and 2.6.

Dr. Selwyn's recommendation of a 5.7% "X" factor proposal has problems. His recommended value of 5.7% is comprised of three parts. A 2.6% amount to reflect TFP, another 2.6% amount to reflect the input growth factor differential, and a 0.5% "stretch factor". The 2.6% TFP amount is based upon Dr. Christensen's earlier study. We differ from the PD in our assessment of Dr. Selwyn's testimony. Once again, we find a TFP that falls within the range of 1.8% to 2.6%. We do not, however, fully accept Dr. Selwyn's analysis. Our previous discussion of the impacts of the "X" factor make it clear that a "stretch" factor is no longer appropriate public policy. Finally, although we find the arguments of Dr. Selwyn on "input price differentials" theoretically interesting, we conclude that there is no basis for concluding that an empirical input price differential will exist in the next three years, or that it exists today.

Indeed, the record contains substantial evidence that the input price differential between the telecommunications industry and the U.S. economy is zero. Dr. Christensen provided data on input price growth for the telephone industry and the overall economy for the years 1949 to 1992,[139] and his analysis demonstrated that input prices for the telephone industry and the rest of the economy grew at virtually the same rate, with only a 0.05% difference.[140] Further, Dr. Christensen testified that although Dr. Selwyn shows an input price differential for the 1984-1992 period, the volatility of that period is so great that the observed differences are not statistically distinguishable from a difference of zero.[141] This same conclusion is reached by Dr. Schmalensee and Dr. Duncan.[142] Based on this record, there is no basis to conclude that the input price differential is different from zero. This result arises because the average of a highly volatile short-term input price differential provides a poor basis to predict future input price behavior.

Based in the totality of the evidence in the record, we conclude that a policy of suspending the application of the price cap formula obviates the need to designate one productivity

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[139] Dr. Christensen (for Pacific) Exh. 6, Att., pp. 17-18.
[140] Dr. Christensen (for Pacific) Exh. 7, Att., pp. 13-15.
[141] Id. at 8.
[142] Dr. Schmalensee (for Pacific) Exh 2, Att. 1, p. 11; Dr. Duncan (for GTEC) Exh. 37, pp. 8-10.

factor as the productivity factor. Our suspension of the formula produces reasonable rates to Californians, and is consistent with the range of productivity estimates presented to us in the record of this proceeding. We note that the range of total productivity factors included in this record was from 1.8 to 2.6. The suspension of the price cap formula effectively equates the "X" factor with GDPPI. This year, the GDPPI is 2.9%, close to the range of productivity factors found in this record. We further reject a productivity factor of 5.0% because it is outdated, no longer reflects today's markets and prices, and is inconsistent with the record. We further find that any use of a price-cap formula that includes an "X" factor of 5.0% is an unreasonable policy. Should the Commission ever intend to end the suspension in the use of this particular price cap formula, a full and new investigation of the appropriate "X" factor would be required.

B. Should the Price Cap Formula be Applied to All Category I and Category II Services, or Solely to Category I Services?

Positions of the Parties

Pacific's primary position is that the price cap formula should be eliminated completely. In the alternative, Pacific recommends that the price cap formula, reflecting a productivity factor of no more than approximately 2%, should

An Updated Study of AT&T's Competitors' Capacity to Absorb Rapid Demand Growth

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2. INDUSTRY AND TECHNOLOGY TRENDS

Advances in transmission, switching, and computing technologies since 1989 have increased the capacity and price-performance of transmission systems, switches, and computing systems for operations and billing used in IXC networks. The following three sections describe some of these advances and show that AT&T's competitors not only have network capacity in excess of that required to handle their existing demand, but that they can also rapidly increase their networks' capacities at minimal cost.

2.1 Transmission

The electronics which drive the throughput of fiber optic cable have increased transmission rates over the last five years and will continue to increase transmission rates dramatically over the next several years. In 1989, the typical electronics on fiber provided transmission speeds of 417 Megabits per second (Mbps), 1.2 Gigabits per second (Gbps) and 1.7 Gbps. During 1990 and 1991, wave division multiplexing (WDM) of 1.2 Gbps and 1.7 Gbps was introduced - doubling the potential capacity to 2.4 Gbps and 3.4 Gbps respectively on a single fiber. During 1992 and 1993, 2.5 Gbps technology on a single fiber became available. In 1994, the ability to have three times 1.7 Gbps on one fiber for a total of 5.1 Gbps became available. Transmission suppliers are promising two times 2.5 Gbps in 1995 - providing 5.0 Gbps on a single fiber. In 1996, transmission suppliers are also promising eight times 2.5 Gbps - providing 20 Gbps on a single fiber; and single wavelength 10 Gbps on a single fiber. In the near future transmission suppliers expect the transmission rate to rise to 40 Gbps on a single fiber. The latest electronics can be deployed on fiber that already exists in the ground. Even those fibers that are currently lit with electronics of slower speeds can be upgraded with electronics of faster speeds.[9]

The next chart illustrates how advances in electronics have increased the potential capacity of a single strand of one directional fiber. The left axis shows the speed of the electronics on a single fiber in Gbps. The right axis shows the number of DS-3s that can be carried on a single fiber pair (multiplying the number of DS-3s by 672 gives the capacity in voice circuits).

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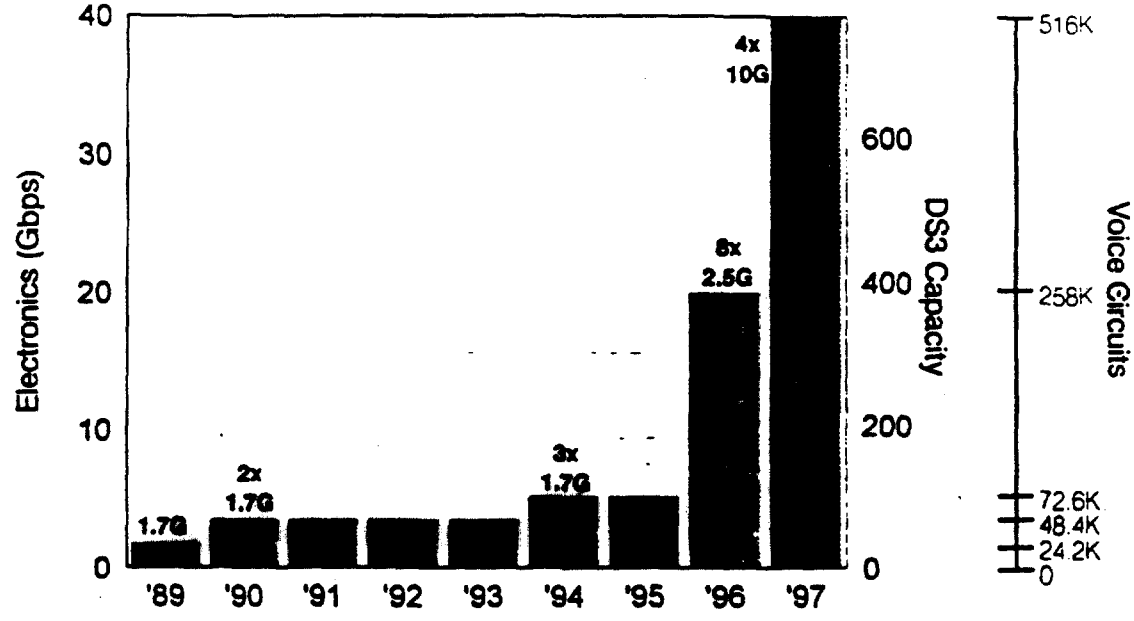
[9] "SONET: Is the Glass Half Full?", B. W. Stuck, *Business Communications Review*, pp. 57-59, Mar. 1995

Figure 2.1 Transport Capacity Increases



Capacity increases of fiber over time

In the past, AT&T's competitors did not generally deploy the fastest possible electronics available in their networks. The following chart shows the potential fiber electronics that existed for the years 1989 through 1993, the number of corresponding DS-3s, and the average number of DS-3s per fiber pair that AT&T's competitors had deployed in their networks.[10] It is believed that the average electronics decline in 1990 may reflect the expansion of access routes with lower capacity requirements and therefore lower electronics speeds.

Table 2-1 Available Fiber Electronics Versus Average Electronics Deployed

Year	Available Electronics	# DS-3s per Fiber Pair	Average Competitor # DS-3s per Fiber Pair
1989	417 Mbps 1.2 Gbps 1.7 Gbps	9 24 36	10.3
1990	2.4 Gbps (2 x 1.2 Gbps)* 3.4 Gbps (2 x 1.7 Gbps)*	48 72	9.1
1991	2.4 Gbps (2 x 1.2 Gbps)* 3.4 Gbps (2 x 1.7 Gbps)*	48 72	12.6
1992	2.5 Gbps	48	13.2
1993	2.5 Gbps	48	16.3
1994	5.1 Gbps (3 x 1.7 Gbps)*	108	Not Available
1995	5.0 Gbps (2 x 2.5 Gbps)*	96	
1996	10 Gbps 20 Gbps (8 x 2.5 Gbps)*	192 384	

* - uses wave division multiplexing (WDM)

[10] Derived from data in FCC "Fiber Deployment Updates" dated Apr. 1990, Apr. 1991, Apr. 1992, Apr. 1993, Apr. 1994, Johnathan M. Kraushaar

The following charts illustrate that since the 1990 Study, the actual and potential capacity installed by AT&T's competitors have grown faster than their own and the industry's switched demand. The Competitors' Transport Capacity - Growth by Component chart illustrates how increases in capacity have been largely due to faster electronics and not just the laying of new fiber in the ground. From 1990 to 1993,[11] the DS-3 capacity of AT&T's competitors has increased nearly 2.5 times, while fiber miles have only increased about 1.2 times.[12] Furthermore, the potential capacity of the existing lit fibers using the latest electronics was more than 4 times greater than the capacity of AT&T's competitors' networks at the end of 1993 as shown on the Competitor Transport Capacity - Potential & Actual chart.

The Competitors' Transport Capacity - Growth by Component chart shows that the increases in competitors' capacity have been the result of increases in three factors: electronics, fiber miles; and percentage of fiber lit. The impacts of each factor were estimated and are shown. This chart was developed by normalizing competitors' DS-3 capacity to one for 1990, the year of the prior study, and showing the contribution of each of these factors over time. The Minute Growth chart to the right shows that minutes, normalized to one in 1990 for AT&T's competitors, have grown at a slower rate than actual capacity. Industry minutes include all IXC minutes.

In order to illustrate the increasing potential capacity of the already lit fiber, the Competitors' Transport Capacity - Potential & Actual chart shows the amount of potential capacity available via re-lighting the existing lit capacity with the fastest electronics. In addition, the total amount of available capacity assuming that the fastest available electronics is used on all fibers is also shown. Competitors' DS-3 capacity is normalized to one for 1990. The Minute Growth chart to the right shows that minutes, normalized to one in 1990 for AT&T's competitors, have grown at a slower rate than capacity.

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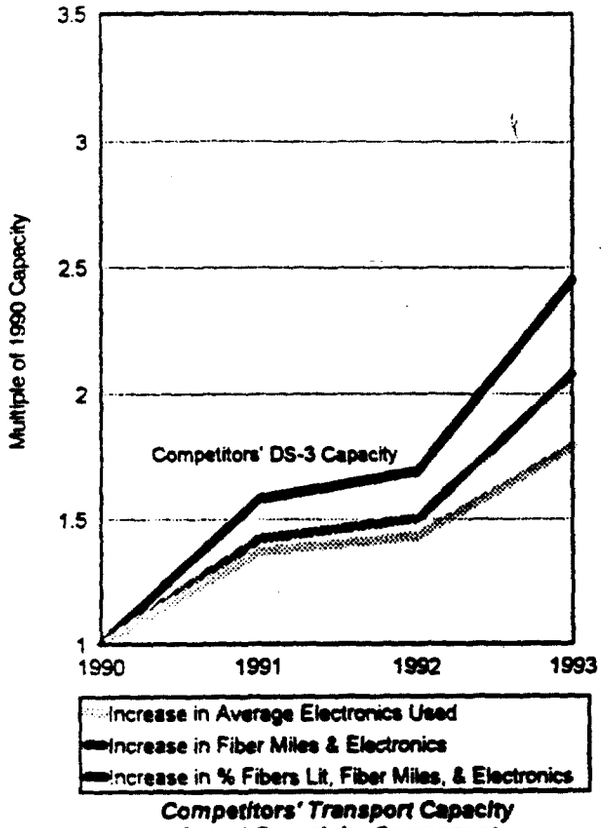
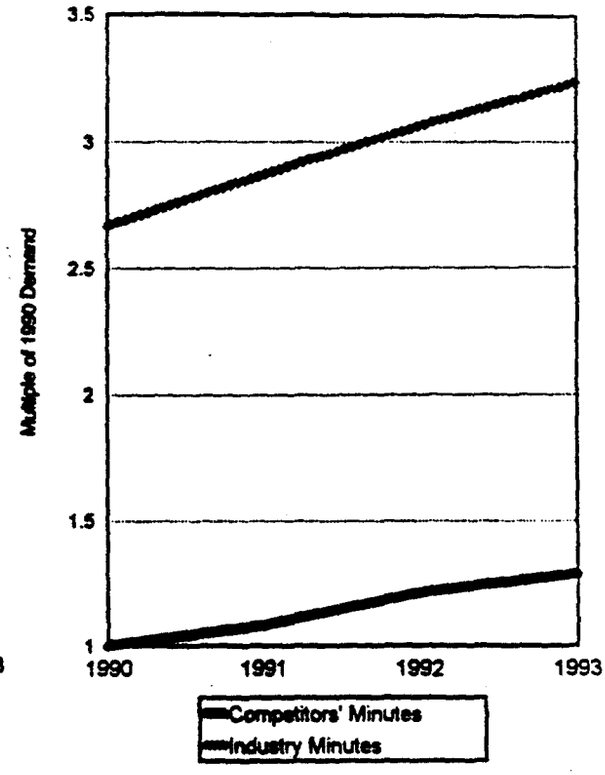
[11] In these charts, 1990 is taken as the reference point. Potential capacity is shown as a multiple of 1990 competitors' DS-3 capacity. Thus, all future values are normalized with respect to the 1990 value.

[12] Derived from data in FCC "Fiber Deployment Updates" dated Apr. 1990, Apr. 1991, Apr. 1992, Apr. 1993, Apr. 1994, Johnathan M. Kraushaar

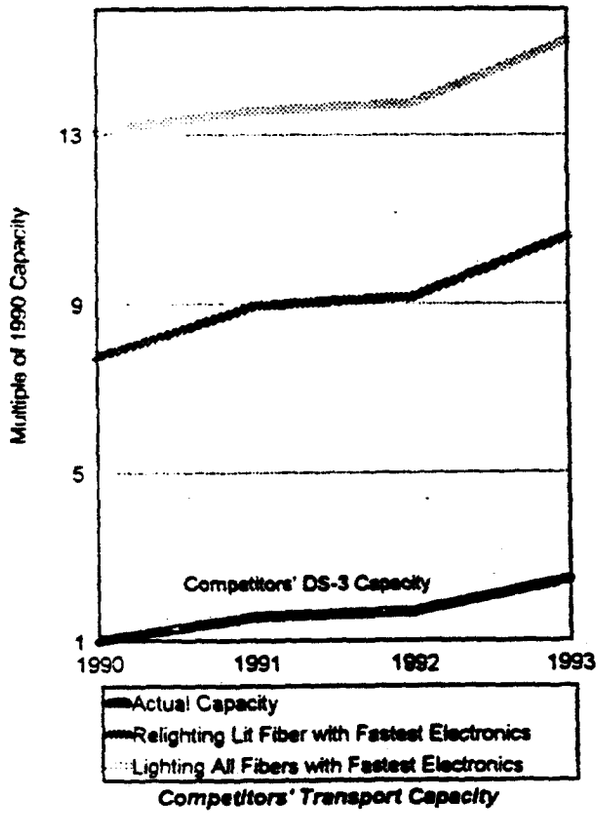
Figure 2.2 Capacity and Demand Analysis



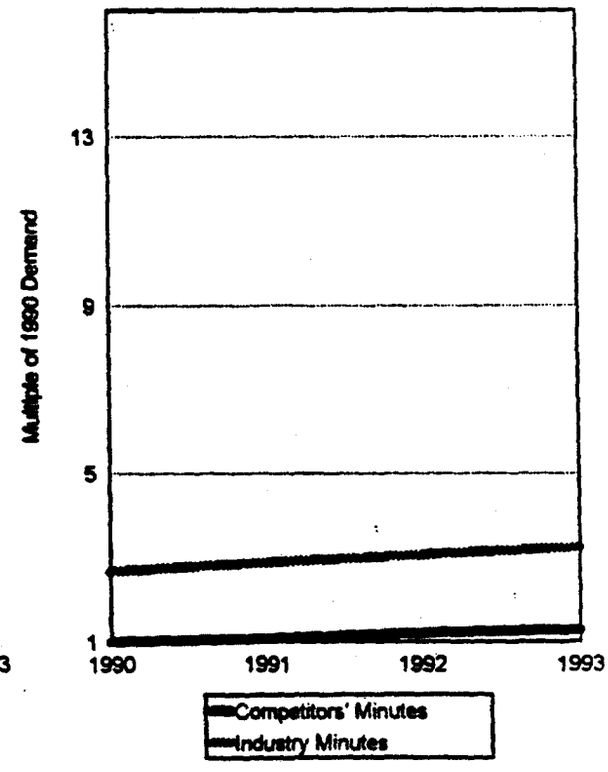
Competitors' Transport Capacity
Actual Growth by Component



Minute Growth



Competitors' Transport Capacity
Potential & Actual



Minute Growth

This analysis clearly illustrates that AT&T's competitors have enough fiber in the ground to carry many times their 1993 demand and that large increases in AT&T's competitors' network capacity could be obtained by lighting dark fibers with the latest electronics as well as upgrading the electronics on currently lit fibers. In fact, MCI and Sprint have recently announced fiber electronic upgrades using synchronous optical network (SONET) technology that will significantly increase the capacity of their networks.

MCI has stated that high speed SONET 2.5 Gbps technology was deployed in half of its network at year-end 1993, and that SONET will be available throughout MCI's domestic network by the end of 1994.[13] Recent announcements from MCI indicate that it plans to boost its transmission speed to 10 Gbps on a single fiber during 1996, and it is currently introducing new fiber optic technologies that will allow 40 Gbps transmission in 1997 or 1998.[14] In 1994, Sprint announced that in the fourth quarter of 1993 it began conversion of its entire network to 2.5 Gbps transmission speeds scheduled to be completed by mid-1996, which will double its circuit capacity.[15] Furthermore, a new technology called bi-directional coupling is now being introduced that allows each fiber to be used in both directions thereby doubling its effective capacity.

From 1990 to 1993, the available DS-3 capacity of AT&T's competitors' networks has increased nearly 2.5 times. Advances in transmission electronics have increased the capacity that a single fiber can carry from 1.7 Gbps in 1989 to 5.1 Gbps in 1994, with a promise of 20 Gbps on a single fiber in 1996 (an astonishing 12 times increase in capacity on a single fiber when compared to possible fiber capacity in 1989). Inter-exchange carriers benefit from these advances, which can increase the capacity of their networks without laying new fiber in the ground.

2.2 Switching

Advances in switching technology over the last five years have increased the maximum port capacity and call handling capability of switches. Northern Telecom Incorporated (NTI) and DSC, the major switching suppliers to AT&T's competitors in the United States, have continually updated the processors they provide with their switches as processor chip technology has advanced. Specifically, Northern Telecom's Series 20 through 40 processors use Motorola's 680x0 microprocessor technology. Northern Telecom's Series 50 through 70 use BRISC (Northern Telecom's version of reduced instruction set computing (RISC)) technology which was specifically designed for telecommunications switching applications. With RISC and the additional innovations of BRISC, the core processor of the DMS switching system accesses, processes, and transmits information more quickly and efficiently. Busy hour call attempts (BHCA) is a measure of a switch's call processing capacity. The following table and chart describes the capacity improvement that Northern Telecom has gained with each switch upgrade in relation to the Series 20 processor as measured by BHCA. This comparison is normalized to the Series 20 processor which was available in 1987.[16]

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13 "MCI Unveils Long Range Vision: networkMCI", MCI Corporate Release by Connie Weaver, Jan. 4, 1994

14 "MCI Targets Key U.S. Cities for SONET Ring Construction San Diego, Los Angeles and Houston First to Get Technology that Instantly Restores Communications if Fiber Optic Cables Are Cut", *PR Newswire*, Mar. 14, 1995

15 "Sprint Bets on SONET", *Communications Week*, Mar. 14, 1994

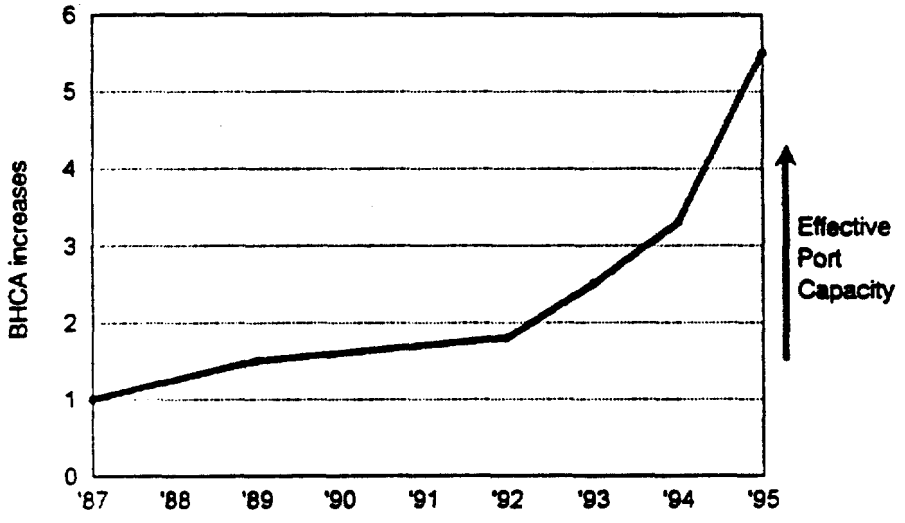
16 *DMS-100 Capacity Planner*, Aug. 1994, Issue 1

Table 2-2 Real-Time Capacity Increases of NTI Switch Processors

Year	Processor Series	Real-time Capacity (Compared to Series 20)	BHCA
1987	Supernode Series 20	1.0	300K
1989	Supernode Series 30	1.5	450K
1992	Supernode Series 40	1.8	540K
1994	BRISC Series 50	3.0	900K
1994	BRISC Series 60	3.3	990K
1995	BRISC Series 70	5.5	1,650K

A graphical depiction of the above data is shown below.

Figure 2.3 Switch Capacity Increases



Real-time capacity increases of Northern Telecom switch processors relative to Series 20 processor

DSC has also upgraded its switch processors to increase call handling capability. Its MegaHub 600E can currently handle 1.2 million BHCA.[17] By increasing the call handling capability, processor upgrades have increased the maximum effective port capacity of the switches. Northern Telecom's DMS-250 Supernode ENET and DSC MegaHub 600E upgrades increased switch capacity to 100,000 effective ports.[18]

The promise of larger switches with greater call handling capability has been realized since the 1990 Study. At present, Northern Telecom and DSC switches both provide effective port capacities of 100,000 and call handling capabilities over 1 million BHCAs. These advances in switching technology have allowed IXCs to more than meet increases in call demand by

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17 *Megahub 600E Specifications*, MegaHub 600E Tandem Switching Family of Products

18 "MCI Switch Upgrade Underway", *Communications Week*, p. 10, Feb. 18, 1991 & "MCI Starts 2-Year Switch Upgrade Program to Save Money for Itself and Users", *Communications Daily*, p. 3, Feb. 14, 1991

upgrading existing switches, which greatly exceed their present real-time switching demands, instead of by the addition of new switches to their networks.

2.3 Computing Systems for Operations and Billing

Computing workstations and mainframes are advancing in capability and function as fast, if not faster, than any other technology needed to support the telecommunications infrastructure of interexchange carriers. Since 1990, computing platforms have continued to rapidly advance and are now significantly faster, smaller, and cheaper - as well as more highly scaleable and more easily migrated to advanced system architectures such as client/server. Each year, component densities, component and system performance, bandwidths, price performance and supporting system software (e.g., operating systems) have advanced. Chip densities, for example, are roughly doubling every 18 months and will continue to do so for the foreseeable future.[19] This in turn has enabled the delivery of more powerful systems with greater feature functionality. More importantly, it has enabled the potential for rapidly expanding the capacities of telecommunications support systems, as needed, to absorb sharply increased demand.

One specific example of the improvement in computing power and price/performance since the 1990 Study is with regard to that of the Complementary Metal Oxide Semiconductor (CMOS) chip technology from Intel. With the introduction of the Pentium chip in March of 1993 the processing power of a single CMOS chip increased more than five times from the 20 million instructions per second (MIPS) of the Intel 486 chip, introduced in August of 1989, to the 112 MIPS of the Pentium.[20] At the same time the price/performance dropped from about $47.00 to $8.00 per MIPS. Similar, if not greater performance improvements have also been achieved by other chip makers, including IBM/Apple/Motorola with the PowerPC, Digital with the DECchip 21064 Alpha AXP and Sun Microsystems' SuperSPARC. In general, the trend for the chip industry over the last decade has been to increase the computational performance of the computer chip and the density of random access memory (RAM) chips roughly exponentially, as shown in the figure below.[21] Thus, dramatic improvements have been achieved in available memory and computing power since the previous study.

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19 "The Future of Workstations", *DATAPRO Information Services*, Mar. 1992

20 "Intel Launches Rocket in a Socket", *BYTE*, pp. 99-108, May 1993

21 "The Future of Workstations", *DATAPRO Information Services*, Mar. 1992