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The Metropolitan Digital Trunk Plant

By J. R. DAVIS, L. E. FORMAN, and L. T. NGUYEN

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This paper statistically describes the physical makeup of the T-carrier metropolitan trunking plant. The basic building block of a digital carrier system is the interoffice span. This span is the collection of all the repeatered lines, or span lines, between two adjacent central offices. Span lines are connected in tandem to form systems. Statistics for interoffice span characteristics of length, cross section, percentage fill and growth are given and discussed for seven metropolitan areas.

I. INTRODUCTION

The metropolitan trunk plant consists of a combination of central office equipment and outside plant cables and electronics. These provide a collection of voice-frequency (VF) circuits to interconnect central offices. At first these circuits were provided solely by loaded VF wire pairs in underground cables located in ducts. As the network grew and traffic increased, ducts became congested and ways were developed to provide additional circuits on the same wire pairs. In 1962, T1 carrier was introduced to provide these circuits and now accounts for a large fraction of the metropolitan trunk plant capacity. In 1975, T1C, operating at twice the bit rate of T1, was introduced and provides a growing fraction of the plant capacity.

The T-carrier plant now contains approximately 160,000 T-carrier systems consisting of some 6,000 interoffice spans providing interoffice connections throughout metropolitan areas. Each T-carrier system provides 24 voice circuits by means of a digital channel bank at each end interconnected by a T-carrier span line (or several span lines in tandem traversing intermediate offices). A D-channel bank converts the 24-voice circuit inputs to a DS1-level, 1.544-Mb/s pulse stream, which is transmitted over the T-carrier span line and is reconverted to 24 voice circuits by the channel bank at the other end. T1C provides 48 channels at the DS1C level, 3.152 Mb/s. The recently introduced

D4 channel bank provides an option for 48 voice circuits for direct interconnection to T1C, as well as 24 circuits for connection to T1.

For the past 3 years, studies have been conducted to characterize both the physical configuration and electrical performance of the metropolitan digital plant to:

(*i*) Allow performance analysis of existing systems and examine the potential for higher-capacity systems in the existing plant.

(*ii*) Provide a base of information to be able to examine the applicability of new transmission facilities.

This paper statistically describes various aspects of the physical makeup of the plant and its short-term growth as projected by current planners. Companion articles in this issue provide field measurement results and a description of automated measurement instruments developed and deployed to obtain them. To study the physical plant, span data were collected from six operating telephone companies (OTCS) covering seven metropolitan areas.

These data represent approximately 1,400 spans or about 25 percent of the total digital spans in the Bell System. However, not all data were available for each span, since each company has its own collection of records, both manual and mechanized. Portions of the span data were obtained from two sources: the physical layouts and cable information were obtained from the outside plant staff, while the growth information was provided by the current planning organization. Since requests for these data were made over a two-year period, the effective date of the information varies from company to company. This paper gives the results of an examination of the physical characteristics of the spans in the metropolitan network. Limited system data from two areas show that the T1 systems average 21 miles long and pass through 4 to 5 spans.

Section II gives statistics of the fundamental parameters of spans for the entire sample, and compares these statistics for the individual metropolitan areas. Section III gives length statistics for individual repeater sections and Section IV relates various aspects of short-term growth projected by the OTC current planners and examines the nature of the growth. Section V summarizes the data. Since individual OTCS are represented only on a sampled basis, the data may not be representative of the entire plant. Thus, each metropolitan area is indicated by a number rather than a name to avoid specific identification. The individual area statistics give an indication of the variation expected over individual metropolitan areas, while the composite statistics give a measure of the overall Bell System metropolitan plant.

II. SPAN STATISTICS

Nearly all metropolitan central offices are interconnected by T-carrier. Span lines, interconnected as needed between terminal offices, form digital systems. Thus, from the planning and provisioning standpoint, the span is the basic building block of T-carrier. This section examines the following span characteristics: length, cross section, cable and apparatus case fill, and the composition of the cable plant in terms of cable size, gauge and insulation type. Results are given for the total sample and the seven metropolitan areas are compared.

The spans and cables included in this sample are qualified in several ways. Only those spans with at least one intermediate repeater are counted in this sample. Short cables connecting two close adjacent buildings or two floors within the same building, called tie cables, are omitted. Only cables that have T-carrier presently operating in them are included. Cables containing only VF trunks often run in parallel with T-carrier cable, but these VF cables are not included. While not all parameters were available for all spans, the maximum number of available data points was used to generate each of the statistics.

2.1 Span length

Span length, or central office-to-central office spacing, is a fundamental span characteristic. The number of manhole repeaters, powering voltage required, etc., are directly dependent upon span length. The extent of the application for a transmission facility with span length restrictions can be determined from a knowledge of the distribution of span lengths.

Figure 1 shows the cumulative probability distribution of span lengths for the total sample. This distribution and others are shown on a normal probability scale so that if the sample were Gaussian or normally distributed, the points would lie on a straight line. Since the curve shows a rather constant bow over the entire distribution, the distribution is not normal; the mean of the distribution is 5.8 miles and the median is 5.4 miles. The standard deviation is 3.2 miles and 68 percent of the spans lie between 2.6 and 8.6 miles, the mean plus and minus the standard deviation. Eighty percent of the spans have lengths between 2 and 10 miles, and 50 percent have lengths between 3.7 and 7.5 miles, the lower and upper quartiles.

The span length distributions for each of the seven metropolitan areas are not normal as well, so quartiles and medians (25, 50, and 75 percent points) are used to compare them. Figure 2 shows the span length distribution for these seven areas, identified by number. The upper and lower bars at the end of the vertical lines indicate the maximum and minimum length in each area. The bar at the center of the box indicates the median, and the end of the boxes are the upper and lower quartiles of the distribution. The width of each box is proportional to the square root of the number of spans in that distri-

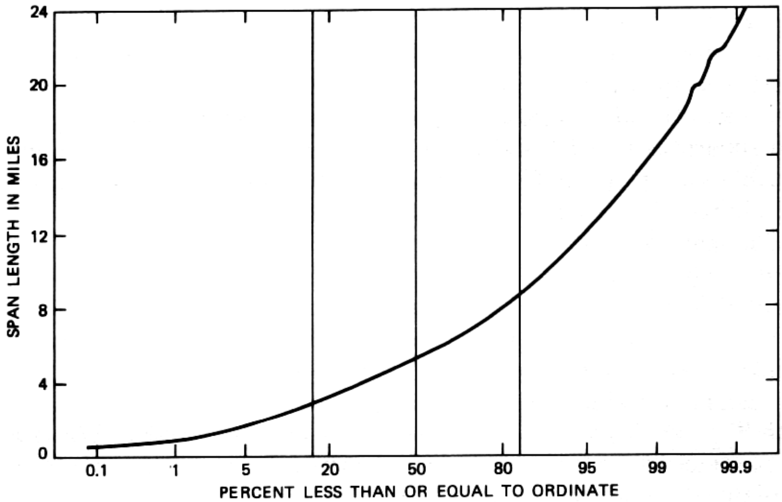


Fig. 1—Distribution of span lengths in seven metropolitan areas. Number of spans = 1398; average 5.8 miles; standard deviation = 3.2 miles.

bution to give an indication of the relative number of spans in each area.

There appear to be two groups of areas: 2, 5, 6, and 7 with medians of about 5.9 miles, and areas 1, 3, and 4 with medians of about 4.6 miles. The 4.6-mile median group has more densely populated metropolitan areas, and thus, has shorter spans. The overall quartiles and median are indicated by the arrows.

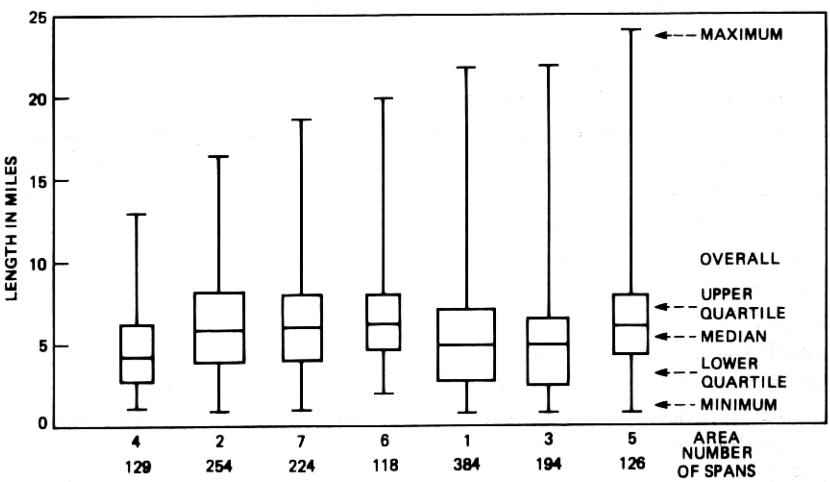


Fig. 2—Distribution of span lengths in seven metropolitan areas.

Six out of seven areas have spans less than one mile long. These short spans generally use 24- or 26-gauge cable and have one intermediate repeater.

2.2 Span working cross section

Span working cross section is defined as the total number of DS1-level signals currently carrying traffic in a span. Maintenance and spare lines are not included. This cross section is on a span basis, and may include systems in several parallel cables. DS1 signals are used as a common denominator; thus, one T1C line with a DS1C-level signal is counted as two DS1 signals.

Figure 3 shows the distribution of span cross sections for the collected sample. For purposes of comparison, each area's cross section was adjusted, using current planning information, to a common date of January 1980, the middle of the period for which growth data have been obtained. As can be seen, this distribution is not normal; the mean is 137, but the median is 90. This mean corresponds to a cross section of approximately 3300 VF trunks, 24 per DS1. Eighty percent of the spans have cross sections between 10 and 330 DS1s, while 50 percent lie between 20 and 180 DS1s. Note that 78 percent of the spans have cross sections less than 200, which can be supplied by a single 900-pair cable.

As with span length, the seven metropolitan areas are compared as shown in Fig. 4. The areas fall into two groups: area 7 with relatively

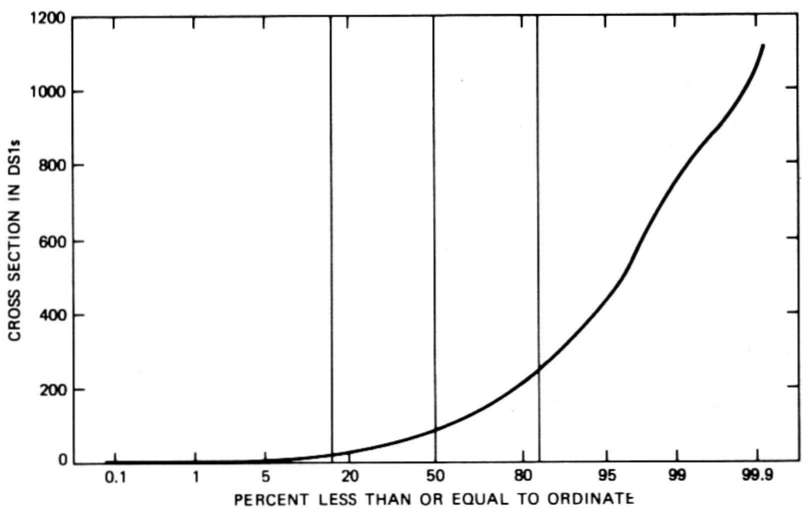


Fig. 3—Distribution of cross section in DS1s in seven metropolitan areas in January 1980. Number of spans = 1339; average = 136.8 DS1s; standard deviation = 151.3 DS1s.

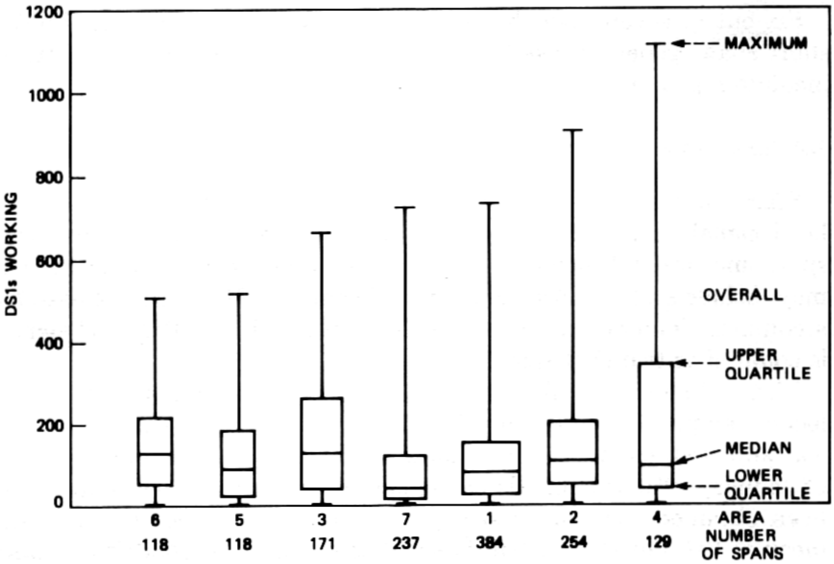


Fig. 4—Distributions of cross sections in seven metropolitan areas.

thinly populated suburbs as well as metropolitan areas resulting in a median of 41, and the other 6 areas with medians ranging from 80 to 130. In addition, areas 3 and 4 stand out by having many spans with cross sections greater than 200, more than twice the overall median. Area 4 has the maximum cross section span in the total sample of 1100 DS1s and a natural corridor of population causing the many high cross-section spans.

2.3 Span length versus working cross section

Combining span length and cross section gives a more complete picture of T-carrier spans than either quantity alone. Figure 5 is a scatter plot of span length versus working cross section, with spans having cross sections greater than 500 DS1s or lengths greater than 16 miles identified by area number.

The plot shows a wide variation of cross section for any given span length. The large cross-section spans are dominated by area 4 as mentioned in Section 2.2. The four area 2 spans near the center of the plot are part of a long backbone route being constructed in this area primarily with T1C. All areas have one or two spans longer than 12 miles which are disjoint from the rest of that area's spans.

The average cross section per 1-mile interval is shown, with the spans longer than 13 miles averaged together. The average cross section shows a slight decreasing trend with increasing span length.

2.4 Theoretical span carrier-pair fill

Various aspects of existing and potential cable occupancy are important when considering the effective use of existing cable to serve future OTC needs. Among the important characteristics are the number of pairs

- currently in use for T-carrier,
- spliced to T-carrier apparatus cases,
- that can ultimately support T-carrier,
- that are spare (no VF, no T-carrier),
- used for VF trunks,
- loaded for VF.

Data collected provide very little VF information, so the cable-fill evaluation is limited to the examination of T-carrier fill.

The first aspect of fill examined is the current occupancy of potential T-carrier pairs. This theoretical fill is defined as the ratio of working DS1s to the maximum number of DS1s a cable can support, according to the engineering rules in effect when the cable was placed. The use of middle-ring binder groups for T-carrier is not used in this analysis. Thus, in accordance with T-carrier engineering practice, a maximum of 200 systems in a 900-pair cable, and 250 systems in an 1100-pair cable is assumed, with corresponding numbers for other cable sizes.

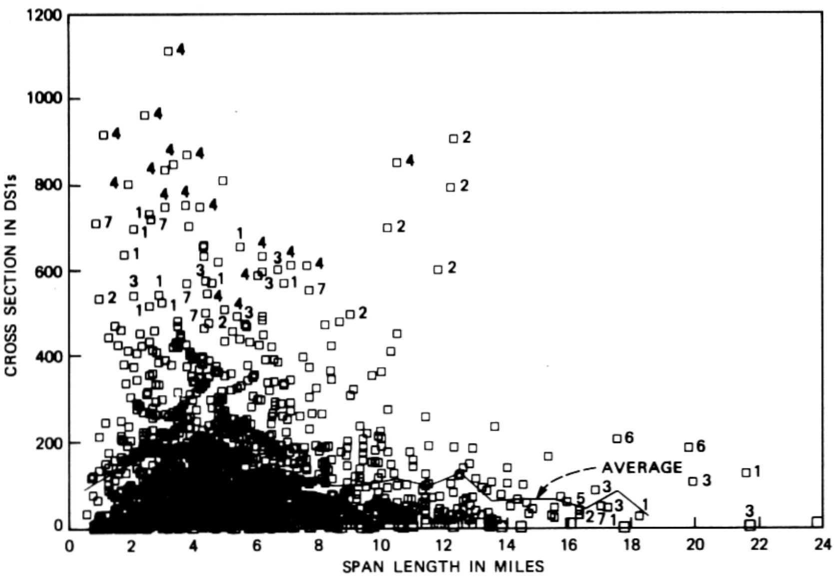


Fig. 5—Span line cross section vs. span length in seven metropolitan areas in January 1980.

Cables in a span are combined so that carrier fill is examined on a span basis. The ultimate capacity of each of the cables was calculated using their current configuration. Resplicing to increase capacity, such as changing from single-cable operation to dual-cable operation, or converting T1 cables to T1C or T1D, was not considered. However, cables engineered for T1C are assumed to fill with T1C, even though they may currently contain T1 electronics.

Four areas provided the type of data needed to calculate carrier fill. Figure 6 shows the distribution of carrier fill on a span basis for these areas. The distribution is nearly normal, with a mean and median of approximately 41 percent, and a standard deviation of 24 percent. Thus, half of the spans are using less than 41 percent of their theoretical T-carrier capacity. In fact, low percentage fill would be expected in small cross-section spans. Recall from Fig. 3 that half of the spans in this seven-area sample have cross sections smaller than 90 DS1s. Most spans use full-size, 900- or 1100-pair cables to make efficient use of duct space. Assuming that all the spans having cross sections of less than 200 DS1s use 900-pair cable, the resulting carrier fill for the seven-area sample is less than 90/200 or 45 percent for half of the spans, reasonably close to the observed value of 41 percent for this four-area sample.

Larger cross-section spans are expected to use more of the available capacity and, thus, exhibit higher-percentage carrier fill. Figure 7 examines the average span carrier fill per 50-DS1 interval versus the

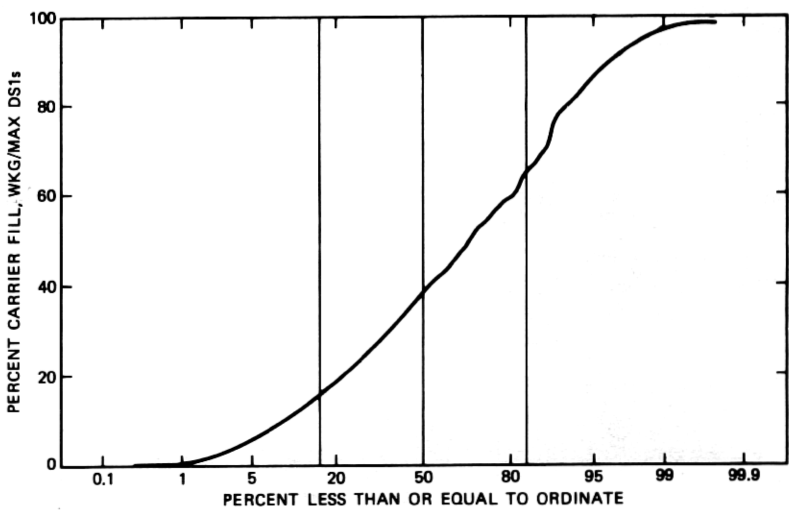


Fig. 6—Distribution of theoretical percent carrier fill on a span basis in four metropolitan areas. Number of spans = 266; average = 40.6; standard deviation = 23.7.

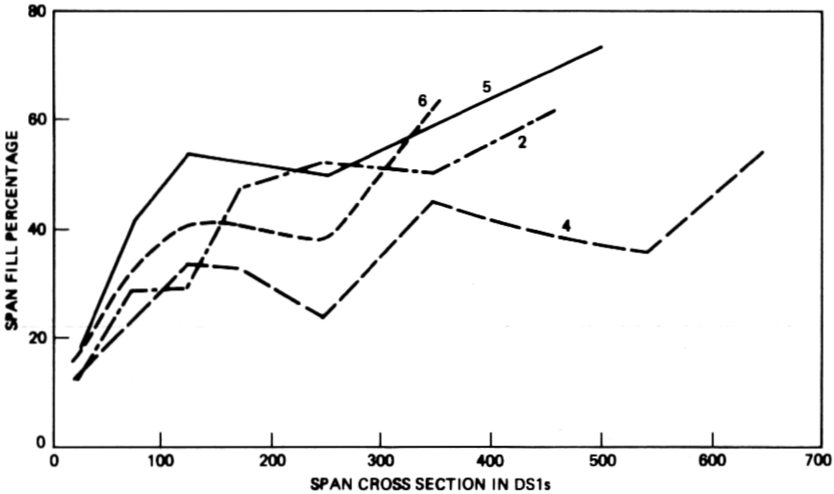


Fig. 7—Theoretical span fill (percent) vs. cross section.

cross section for the same four areas. All four areas show the expected trend of increased-percentage carrier fill with increasing cross section. However, since only a small percentage of these spans have large cross sections where higher-percentage fills lie, the average carrier fill is only 41 percent. The fill of area 4 is lower than the others because dual-cable operation predominates in this area, whereas single-cable operation is prevalent in the other three areas. Although the cables can be completely filled with T-carrier in dual-cable operation, and the fill here is calculated on that basis, the cables were placed when large VF trunk requirements existed, and the cables were used for both purposes. Most dual-cable operations are not and will not be filled with T-carrier, except for newer cables specifically dedicated to T-carrier.

Combining the spans in these four areas results in the distribution of average theoretical carrier fill versus cross section of Fig. 8. Omitting the spans of area 4 (see the dashed line), with their predominant dual-cable operation, gives an increased average carrier fill for all cross sections as shown in the figure. To examine the reasonableness of this carrier fill, assume that all T-carrier cables are 900-pair, single-cable operation. Also, assume that each cable is fully used for carrier (200 systems) before a new 900-pair cable is placed. Then, the span carrier fill, versus cross section, would be as shown by the straight line rays in Fig. 8. The first cable would be completely filled at 200 systems, then a second cable would reduce the percentage fill to 50 percent. The span would then be completely full at 400 systems, requiring a third 900-pair cable, at which time the fill would drop to 67 percent, and so forth.

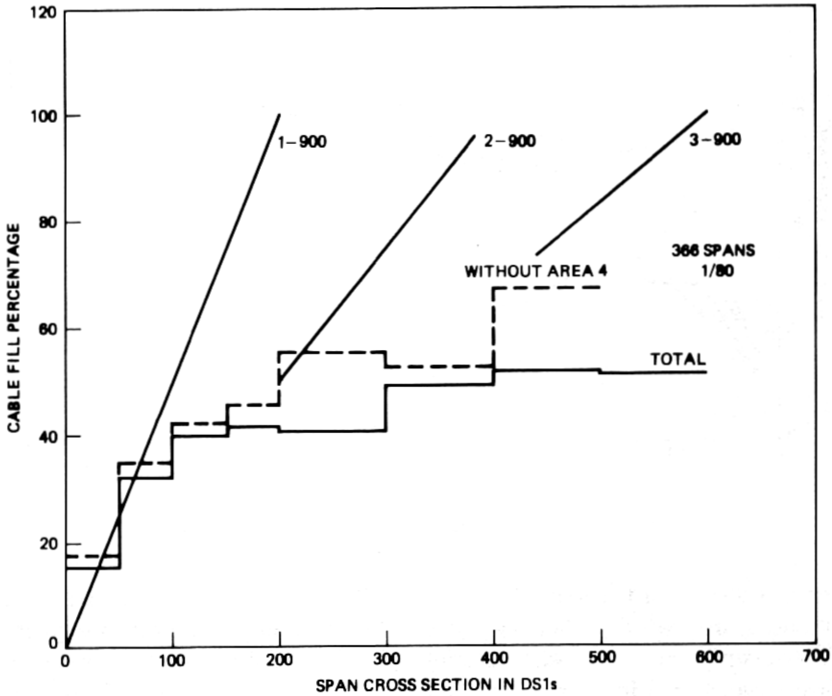


Fig. 8—Theoretical span carrier fill vs. cross section.

Spans with cross sections less than 100 (recall from Fig. 3 that this amounts to 58 percent of the total) follow the one 900-pair cable curve fairly well. However, for cross sections greater than 100, almost no spans have percentage fills as high as expected from this model. This deviation suggests that new cable placement for the metropolitan trunk plant has not been triggered by exhausting T-carrier pair capacity, but rather by VF trunk needs. Pairs remaining for use when additional cable is placed—generally T-carrier pairs—will be enough to reduce T1 fill measurably, but not enough to supply VF trunk needs and delay significantly the placement of additional cable. When cables are added, T-carrier is generally placed on the additional cable, as well as the original for reliability purposes, yielding lower carrier fill for the span than would be the case if the carrier had triggered the exhaust. Limited data show that large working VF complements frequently occupy potential T1 binder groups, in addition to VF binder groups, supporting this hypothesis.

While the carrier fill is relatively low, the percentage of pairs used in the cables is much higher. On the average, more than half the active pairs in a cable and, thus, in a span, are not capable of supporting T-carrier, and are generally loaded for VF trunks. As indicated above, limited data indicate that the fill of the VF pairs is high, frequently such that binder groups that could support T-carrier are used for VF in addition to the others. Areas 2 and 7 have indicated that they are willing to roll, and have rolled, active VF trunks to free pairs for T-carrier. Thus, the carrier fill as derived here is consistent with the OTC view for these areas, since pairs currently used for VF trunks could be made available for T-carrier. However, area 4 does not usually roll active VF. In addition, although the other areas will roll VF, certain cables may have been designated for no additional T-carrier for other reasons, such as poor cable condition. This factor would increase the carrier fill from the OTC standpoint, since a particular cable with relatively few systems may be considered fully used for T-carrier by the company.

2.5 Apparatus case fill

The previous section examined the use of the ultimate span capacity, i.e., the fraction of the maximum number of T1 lines a span could support that are currently in use. This section examines the apparatus-case fill on a span basis, defined as the ratio of the number of working DS1s to the number that could be supported by the existing apparatus cases. This percentage measures how effectively apparatus cases are being used, and also indicates the growth that can be accommodated without additional splicing.

The distribution on a span basis of apparatus-case fill is shown in Fig. 9 for the four areas that supplied these data. The average and median are both 56 percent, with a standard deviation of 26 percent. This median of 56 percent implies that half of these spans can accommodate a 79-percent increase in working DS1s before a new apparatus case is needed. Of course, some spans are nearly full; 12 percent have apparatus-case fills greater than 90 percent. However, most spans have significant reserve apparatus-case capacity.

Area 6 splices the maximum number of cases the cable can support when initially equipping for T-carrier. Removing these spans from the population results in the distribution shown by the dashed line. The average is now 64.9 percent, and the median 67 percent, both an increase in use. However, the median of 67 percent implies that half the spans in the remaining three areas can accommodate a 49-percent increase in working DS1s before a new case is needed, which still indicates a significant reserve.

The low-percentage apparatus-case fill is likely to occur on low cross-section spans, where growth may be slow and a case may not fill for some time. Figure 10 shows this to be the situation. The higher cross-section spans tend to have higher-percent apparatus-case fill, as shown by the line indicating the average fill per 200-DS1 step. How-

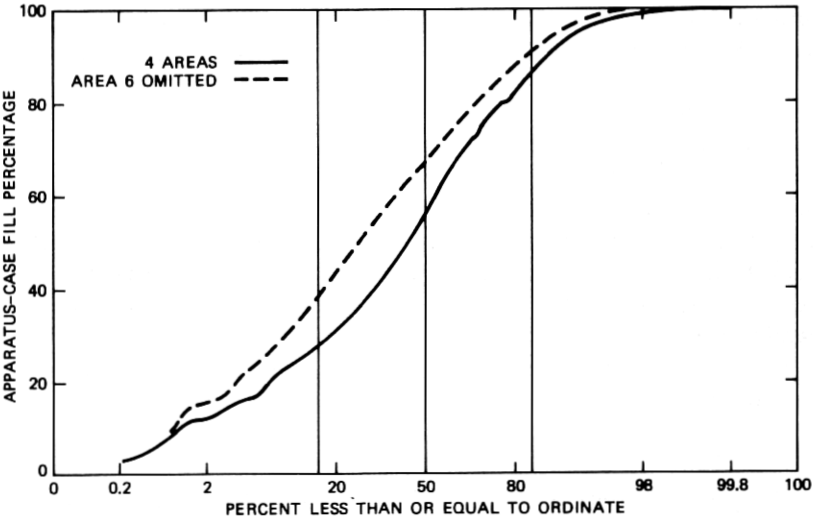


Fig. 9—Distribution of percent of apparatus-case fill on a span basis in four metropolitan areas. Number of spans = 445; average = 55.9; standard deviation = 25.5.

ever, there is a wide variation in percentage apparatus-case fill for a given cross section. There are some high cross-section spans that have many spare apparatus cases as shown by the family of curves that indicate the number of spare apparatus cases for a given cross section and percentage fill. For example, consider the 8 spare-case curve. A working cross section of 200 DS1s requires a minimum of eight apparatus cases; if there were eight additional cases on such a span, the percentage fill would be 50 percent. This number of additional cases assumes all unused slots are combined into the minimum number of apparatus cases; actually, there may be no completely empty apparatus cases in a particular span, rather, many partially filled ones.

Fifteen spans with working cross sections greater than 400 have eight or more spare apparatus cases. In fact, 39 spans (11 percent) have 16 or more spare cases. Most of these low percentage-fill spans have smaller cross sections, as previously indicated. The points representing spans from area 6, which have more than 8 spare apparatus cases, are identified by the number 6. Almost all spans with more than 16 spare cases are from this area. However, there are spans (unmarked) from the three other areas which have from 8 to 16 spare cases. Thus, all areas contain spans with significant reserve apparatus-case capacity.

Three factors contribute to this 56-percent average fill. First, system rearrangements can cause a decrease in span carrier requirements which results in one or more T1 span lines being turned down. These lines will probably be reused in the future, but this churn causes some formerly active span lines to be depowered and left inactive. In this examination of apparatus-case fill, any such lines are counted as empty case slots. Second, most OTCs will splice several apparatus cases at a time when equipping a cable for T-carrier. As mentioned, area 6 splices the maximum number of cases the cable can support when equipping for T-carrier. This procedure increases reliability by eliminating future disturbances of the cable sheath and splice cases, but also results in empty apparatus cases for some time. Third, cables originally placed in T-spans to satisfy loaded VF requirements are used to diversify T-carrier. This diversity leads to more partially equipped apparatus cases. For example, instead of one case 100-percent full on one cable, there could be two cases 50-percent full, one on each of two parallel cables.

2.6 Cable plant

T-carrier was originally engineered for use in most common VF trunk cables. Thus, T1 is found in a variety of cable gauges-19-, 22-, 24-, and 26-gauge cable, and on sizes of from 50 to 1800 pairs. Spans which change cable gauge and size between offices are used, as well as spans with cables containing more than one gauge in the same sheath, called composite cable. Both directions of transmission can be in the same

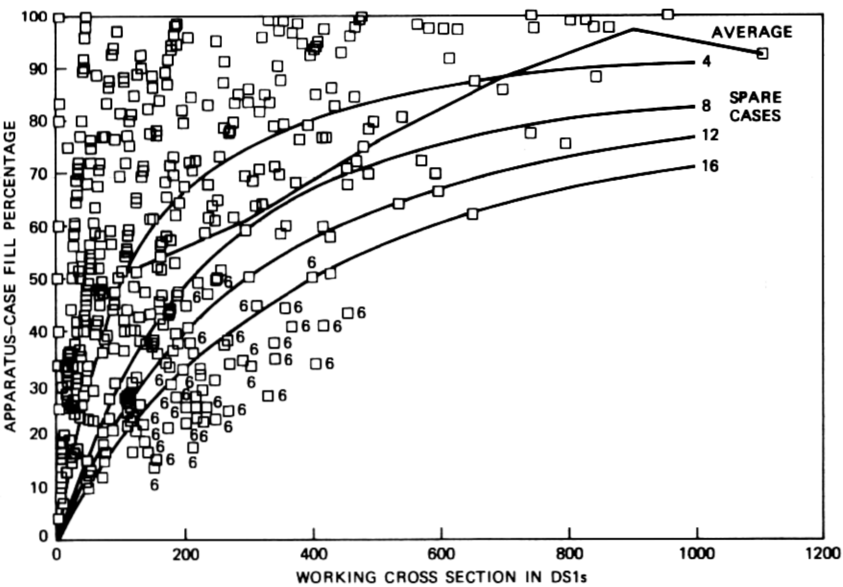


Fig. 10—Apparatus-case fill vs. working cross section in four metropolitan areas.

sheath, called single-cable operation, or two separate cables can be used, one for each direction, called dual-cable operation. This section examines the nature and use of the outside plant cables in the metropolitan T-carrier plant. The cable size, gauge, type, insulation, and type of operation are described in the following paragraphs.

Cable size by plant mileage is displayed in Fig. 11 for the six metropolitan areas for which data are available. Spans that use cables of different sizes in tandem between central offices, or odd cable sizes such as 707 or 812-pair, are classified as "other." Area 2 has the most uniform plant with 63 percent 900-pair, 26 percent 1100-pair, and very little other. Area 7 is at the other extreme with 65 percent other. This area, unlike the others in this figure, combines subscriber pairs with VF and T-carrier-supplied trunks in a common sheath to such an extent that the cables generally decrease in size with distance from the central office as subscriber pairs leave the cable. Other areas shown here maintain separate cables for trunk circuits. Area 1 (not shown) also combines subscriber and trunk in common sheaths and cable records are dispersed throughout individual districts, making collection and analysis impractical. The large 1500- or 1800-pair cables are generally

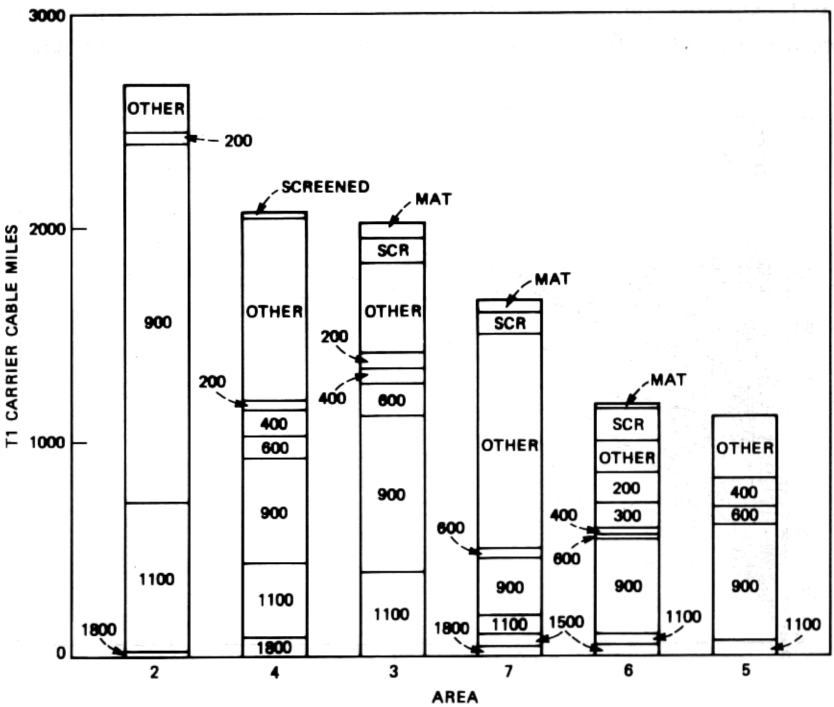


Fig. 11—Cable sizes and types in six metropolitan areas.

used in short spans connecting large downtown offices. The 1100-pair cables are used in spans where slightly more VF trunk requirements are anticipated than could be supplied by 900-pair. The most common single cable is 900-pair, accounting for 39 percent of the total cable mileage. The smaller-size 200- through 400-pair cables are often used in aerial dual-cable operation in the suburbs.

Metropolitan Area Trunk (MAT) and other screened cables have been counted separately since their built-in shield permits full-fill T-carrier operation in a single sheath. These screened cables account for 4 percent of the total cable mileage. MAT cable, comprising approximately 1 percent of the plant, is 1200- or 1400-pair. Of the remaining 3 percent accounted for by other screened cables, 63 percent is 900-pair, 22 percent is 600-pair, and the rest smaller sizes. Recent cable installations are primarily MAT or other screened cables, with sizes of 1200-pair or more being MAT, and 900-pair or less being other screened. Since MAT is now available in smaller sizes, new smaller size cable installations will probably use MAT. This sample contains 10,644 cable miles. Since this cable sample is about 20 percent of the total T-carrier plant, the total T-carrier cable mileage is estimated to be 50,000 miles.

Cable gauge by plant mileage is displayed in Fig. 12 for the six metropolitan areas for which data are available. Spans that use more than one gauge in tandem between central offices, as well as 25 (MAT) and 26-gauge cables, are also classified as other. On this basis, area 2 again has the most uniform plant with 93 percent being 22-gauge cable. area 7 is still the most heterogeneous with 40 percent other. Again, this irregularity is a result of subscriber and trunk pairs occupying common sheaths. The 19-gauge cable is typically used when extra-long intermediate sections are needed or to permit full-fill T1 operation at 6000 foot spacings. (See Section III for intermediate section details.) The 22-gauge cable accounts for 80 percent of the total mileage for the aggregate sample, and at least 75 percent for each of the areas except area 7. Much of the other cable mileage contains 22-gauge sections. Often one of these other cables will have a 24-gauge section adjacent to the central office, then 22-gauge cable until the end section adjacent to the next office, where 24- or 26-gauge is again used. Spans consisting of entirely 24-gauge cable are generally short, downtown spans which usually contain 1500- or 1800-pair cables.

Cable insulation type is nearly all pulp. Of the total mileage, 92 percent is pulp-insulated and the remaining 8 percent is PIC. Metropolitan Area Trunk cables, 1 percent of the total mileage, are included with the other PIC cables. The amount of PIC by area ranges from 11 percent in areas 3 and 4 to less than 1 percent in area 2.

Cable operation by plant mileage is shown in Fig. 13 for all seven metropolitan areas. Single-cable operation, having both directions of

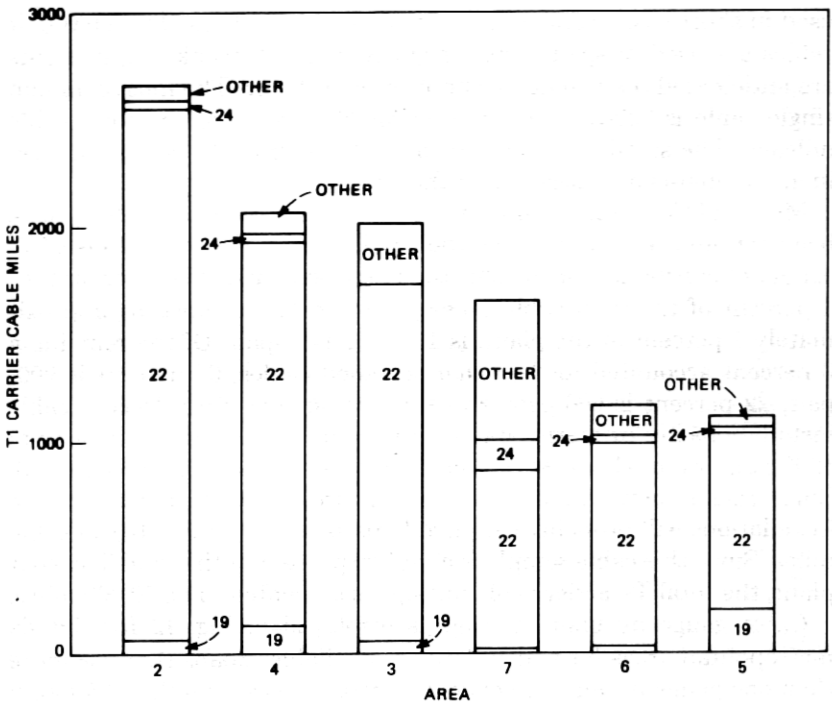


Fig. 12—T1 carrier cable gauges in six metropolitan areas.

transmission in one cable sheath, limits carrier fill to somewhat less than half of the pairs for most cables. Dual-cable operation, having each direction of transmission in a separate cable, allows full carrier fill. MAT and other screened cables are again counted separately since they provide both directions of transmission in a single sheath and allow full carrier fill. Single-cable operation accounts for 66 percent of the mileage, dual-cable 30 percent, with MAT and other screened cable accounting for only 4 percent. However, since new installations are predominantly MAT or other screened cable, this percentage is increasing with time. Higher cross-section areas 3 and 4 frequently use dual-cable to support their dense routes.

III. REPEATER SECTION INFORMATION

T-carrier system performance is determined by the performance of individual repeater sections, which in turn depends on section parameters, chiefly section loss. In this section, the repeater-section statistics of the T-carrier network are investigated. We discuss distributions of section lengths which include intermediate sections of all gauges, 22-

gauge pulp sections only, the longest section per span, and the number of repeaters per span.

3.1 Intermediate section distribution

Intermediate sections are defined as those between two outside plant repeater locations; sections adjacent to a central office (end sections), which are limited in length to less than the maximum allowed for the intermediate sections, are excluded. Figure 14 shows the distribution of intermediate section lengths combined for all metropolitan areas. As seen from the figure, the average section length is 5.3 kft and the standard deviation is 1.03 kft. Ninety-six percent of the sections are less than 6.3 kft, the engineering limit for T1 systems operated on 22-gauge pulp. The remaining 4 percent longer than 6.3 kft are comprised of either 19- or 22-gauge air core PIC cables for which the maximum allowable section length is 9.5 and 6.9 kft, respectively.

The separate distribution of intermediate section length for each of the seven metropolitan areas are coplotted in Fig. 15, showing the contribution of each area to the overall distribution. The mean section lengths vary from 5.0 to a maximum of 5.75 kft and the standard deviation from 0.90 to 1.12 kft. All sections above 7 kft are from only

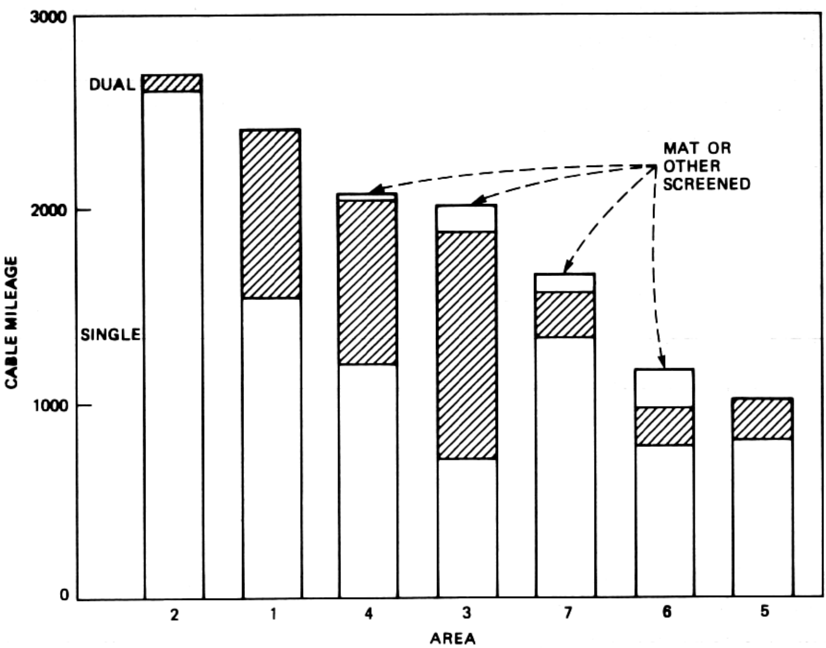


Fig. 13—Single- and dual-cable operation in seven metropolitan areas.

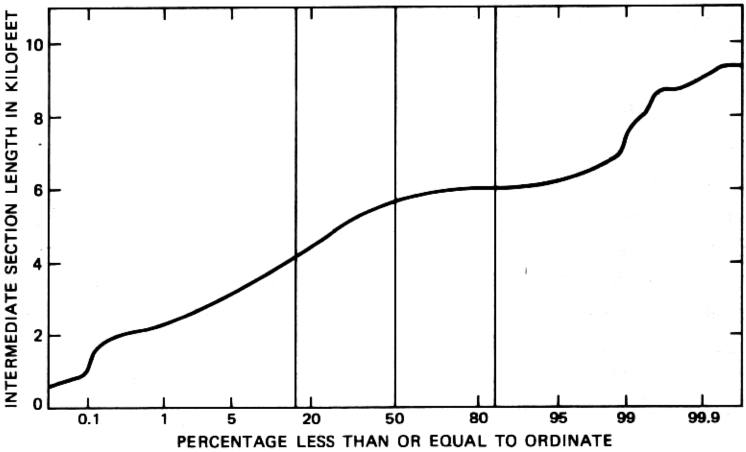


Fig. 14—Distribution of intermediate section length in seven metropolitan areas. Number of points = 4812; average 5.30; standard deviation = 1.03.

three areas, each of which utilize a larger than average percentage of PIC cables. Note that all areas have sections under 4 kft, ranging from 4 percent to 20 percent of the individual areas' distributions.

As indicated in Section 2.6, over 70 percent of the metropolitan digital plant in this survey is made up of 22-gauge pulp cable sections; the distribution of these section lengths is shown in Fig. 16. Assuming a cable loss of 5.2 dB per kft at T1's Nyquist frequency, the average length of 5.3 kft translates to 27.6 dB of insertion loss. As expected, no sections exceed 6.3 kft, the maximum repeater spacing allowed for 22-gauge pulp. Except for two areas with highest means (5.61 and 5.73 kft), the rest of the samples have similar characteristics with mean values ranging from 5.2 kft to 5.38 kft and standard deviations from 0.65 kft to 0.93 kft, as shown in Fig. 17. Only 10 to 30 percent of the sections are less than 5.0 kft.

3.2 Longest intermediate-section distribution

The performance of a set of digital span lines is largely controlled by the highest loss (usually longest) section in the span. Figure 18 shows the distribution of the longest section per span for all seven areas combined. The shape of the longest-length distribution is very similar to the overall length distribution presented previously. The mean is slightly higher (5.63 kft vs. 5.30 kft) and the standard deviation lower (0.84 kft vs. 1.04 kft). More than 80 percent of all spans have at least one section longer than 5.0 kft. Figure 19 displays the distribution of the highest-loss section per span, where the loss data are either provided by the participating operating companies or derived by

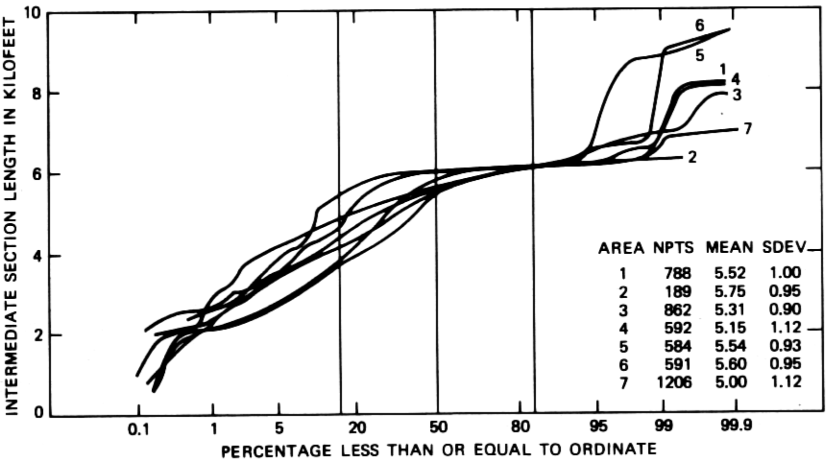


Fig. 15—Distribution of intermediate-section length in seven metropolitan areas. Number of points = 4812.

applying the appropriate cable-engineering loss to each cable section. Note that all sections have less than 33 dB of loss and 50 percent of the spans have no section loss greater than 30 dB. There are, however, remarkable differences among the areas at the lower-loss portion of the distribution, as shown in Fig. 20. For example, the percentage of spans with longest section loss less than 28 dB varies from as little as 2 percent in one area to about 30 percent in others.

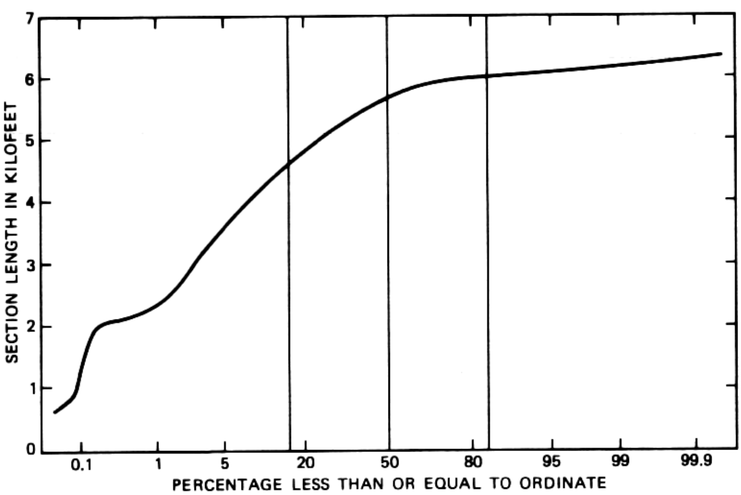


Fig. 16—Distribution of intermediate section length (22-gauge cable) in six metropolitan areas. Number of points = 2538; average = 5.37; standard deviation = 0.83.

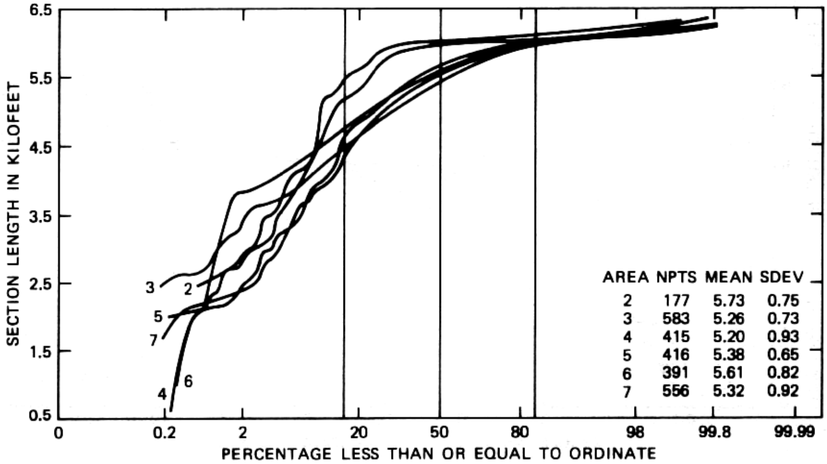


Fig. 17—Distribution of intermediate-section length (22 gauge cable) in six metropolitan areas. Number of points = 2538.

3.3 End-section distribution

Figure 21 shows the distribution of the end sections—those adjacent to a central office. The mean is 2.86 kft and the standard deviation is 0.65 kft. As with the intermediate section lengths, the mean value is well within the engineering limitation for a T1 end section with 22-gauge pulp cable (4.5 kft). Approximately 5 percent of sections use 19- or 22-gauge PIC cable and exceed the maximum 22-gauge pulp spacing.

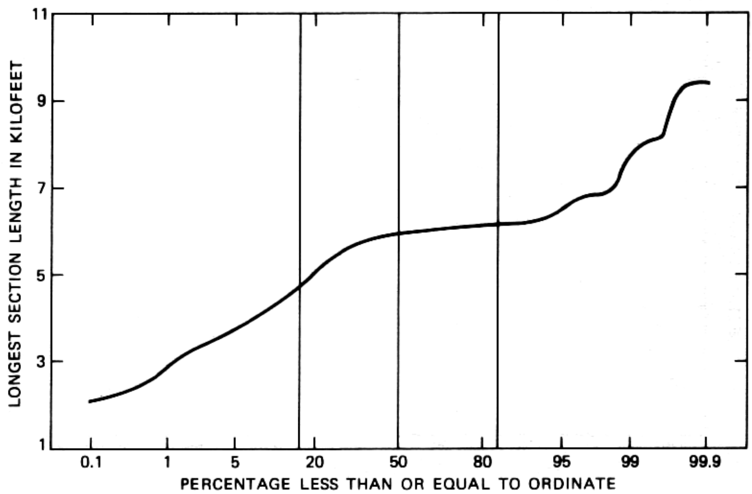


Fig. 18—Distribution of longest section per span in seven metropolitan areas. Number of points = 1016; average = 5.63; standard deviation = 0.86.

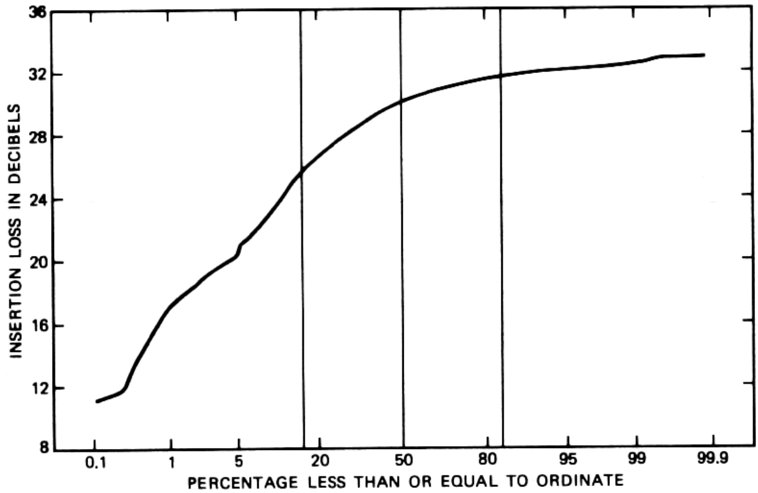
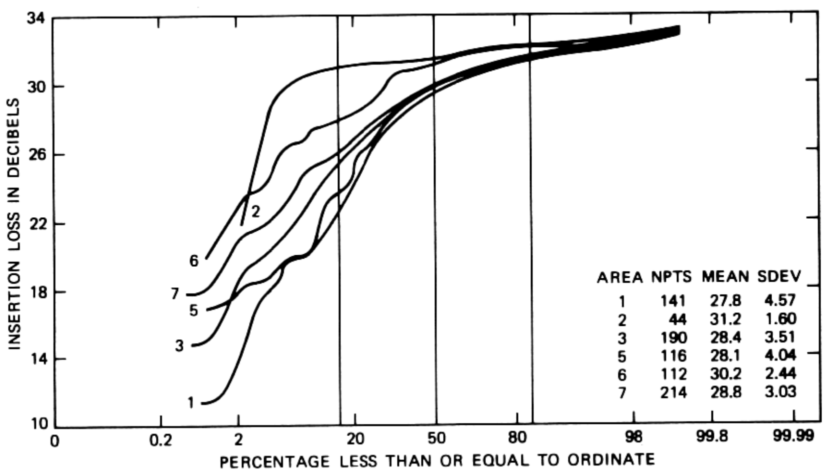


Fig. 19—Distribution of maximum intermediate-section insertion loss per span in six metropolitan areas. Number of points = 817; average = 28.77; standard deviation = 3.59.

All areas have similar end-section distributions, as shown in Fig. 22. The mean and standard deviations are within a few hundred feet of each other.

3.4 Distribution of the number of sections per span

Figure 23 shows the distribution of the number of repeater sections per span (i.e., number of tandem outside plant repeaters plus one).



AREA	NPTS	MEAN	SDEV
1	141	27.8	4.57
2	44	31.2	1.60
3	190	28.4	3.51
5	116	28.1	4.04
6	112	30.2	2.44
7	214	28.8	3.03

Fig. 20—Distribution of maximum intermediate-section insertion loss per span in six metropolitan areas. Number of points = 817.

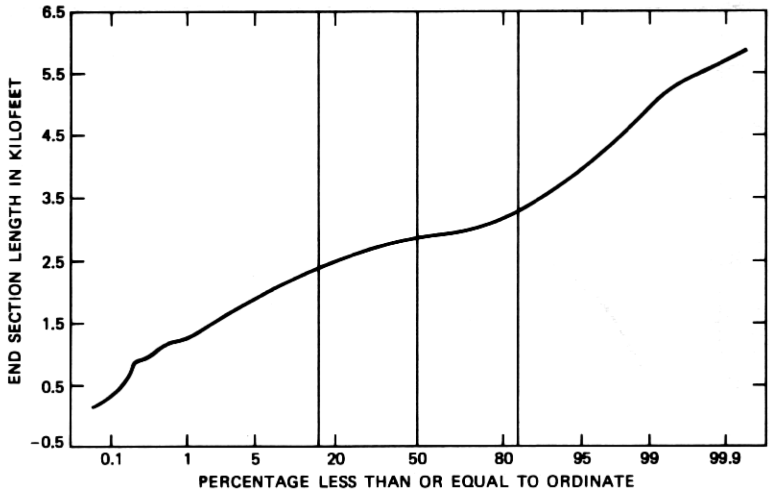


Fig. 21—Distribution of end-section length in seven metropolitan areas. Number of points = 2029; average = 2.86; standard deviation = 0.62.

The average number of sections per span is 6.62, with the longest span having 21 sections. Nearly 85 percent of the spans have between 4 and 11 sections. Only two areas differ slightly from the rest of the sample—as shown in Fig. 24—having average values of 7.1 and 7.38 sections per span. One area, area 6, has longer than average span length, as would be expected. The other, area 7, not only has slightly longer than average distances between central offices, but also uses conservative

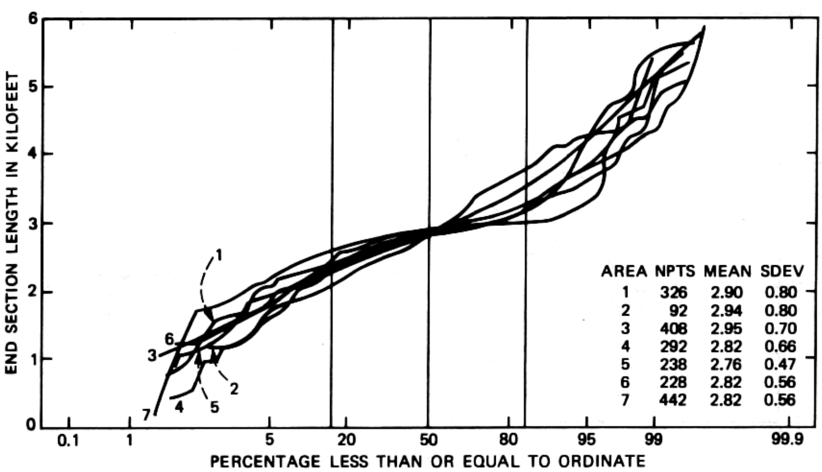


Fig. 22—Distribution of end-section length in seven metropolitan areas. Number of points = 2026.

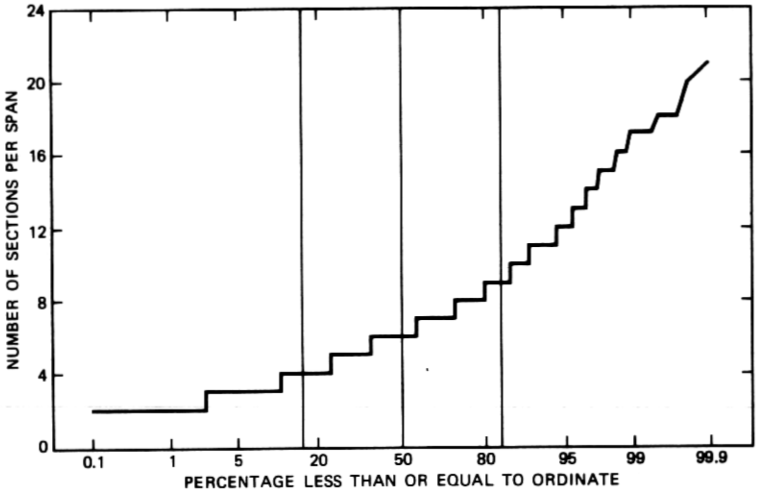


Fig. 23—Distribution of number of sections per span in seven metropolitan areas. Number of points = 1041; average = 6.62; standard deviation = 2.90.

engineering rules, forcing shorter section lengths. Both of these factors increase the number of sections per span.

IV. SPAN GROWTH

The efficient use of the present plant, and the alternatives and applications for various possible new transmission facilities require an understanding of not only the present state of the plant but also of the nature of its growth. Not only is the amount of growth important, but an understanding of the pattern of this growth is needed as well. In this section, span growth means the increase in span lines of the network, usually provided by adding span lines in existing spans. New spans are being added at a rate of less than three percent per year, and have a small effect on the total number of span lines added.

It is important to note that span-line growth is not equivalent to system growth. Since many systems with diverse originating offices use the same span, growth in that span may be due to increased requirements for many different systems, none of which may originate in that span. Conversely, since a single system passes through many spans, the placement of one new system requires an additional span line in several spans. Since the span is the fundamental building block of the T-carrier network, span-line growth is described in the following sections.

To examine the span-line growth, data were requested from six OTC current planning groups. These requests occurred over two years so that the growth projections begin at a different time for each area. In

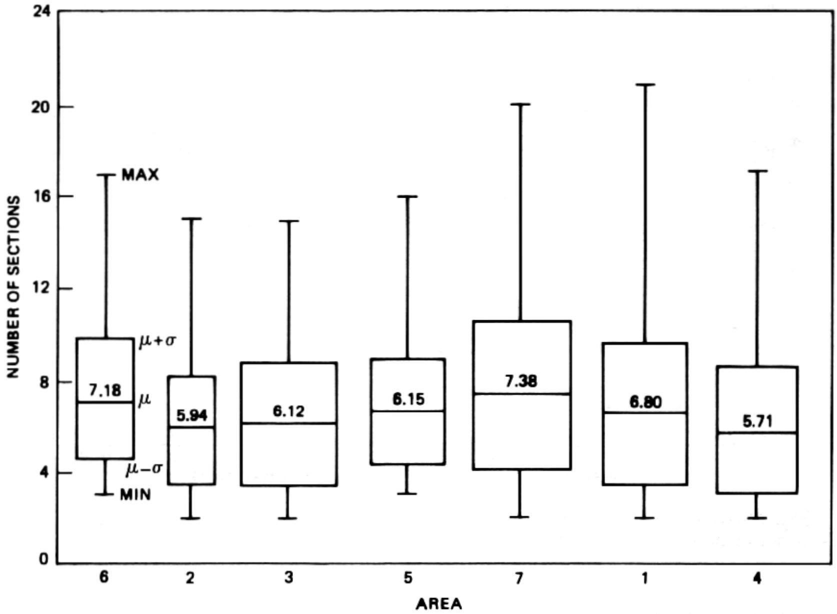


Fig. 24—Number of sections per span.

addition, each planning group projects their growth for different time intervals. Starting times ranged from January 1977 to January 1978, while projection intervals varied from 2 to 5 years. For five areas, this span-line-growth data represent the projected number of working DS1s each year for each span. For area 5, span-line growth was derived from the data given for the number of voice circuits to be provided by T-carrier. For this growth, 100-percent circuit fill of T-carrier line additions was assumed.

The number of span lines versus time for each area, the span-line growth average on a per-year basis, and network growth patterns are discussed in the following section.

4.1 Growth versus time by area

The span-line growth for all spans in each area was combined to produce a plot of growth for each area. Since maintenance lines and backbone spare lines are not included in this growth, the total span-line additions are higher than shown by 4 percent. Figure 25 shows the number of span lines versus time for six areas. Note the different starting dates and growth projection intervals. The number of span lines has been normalized to unity at the starting date for each area.

Reference lines of 5 and 10 percent growth per year are given. Areas 1, 2, 6, and 7 have an average growth rate over their respective years of from 7 to 8 percent. Area 4 planned a year of substantial growth in 1979 to provide service for two No. 4 ESS machines. The low-growth rate of about 4 percent for area 5 was derived from the number of voice circuits to be provided on T-carrier, and may be conservative. This method assumes 100-percent channel-bank fill—or that only one additional T1 span line is required for each group of 24 new voice circuits, which is often not the case. Limited data indicates channel-bank fills of about 80 percent, which would bring the growth of area 5 to about 5 percent.

4.2 Average yearly growth

Combining span growth data from different areas is complicated by the different starting dates and projected growth intervals for each area. Also, individual spans vary widely in year-to-year growth. One reasonable way to compare individual spans is to use an average yearly growth, the average number of DS1s added per year for each span. This average yearly growth is a measure of the growth of each span and smooths year-to-year variations, enabling comparison of spans from all areas. An average yearly growth of 24 DS1s per year is equivalent to adding one T1 apparatus case or one-half T1C apparatus case per year.

The examination of average yearly growth gives insight into the pattern of span-line growth in the operating companies. Knowledge of

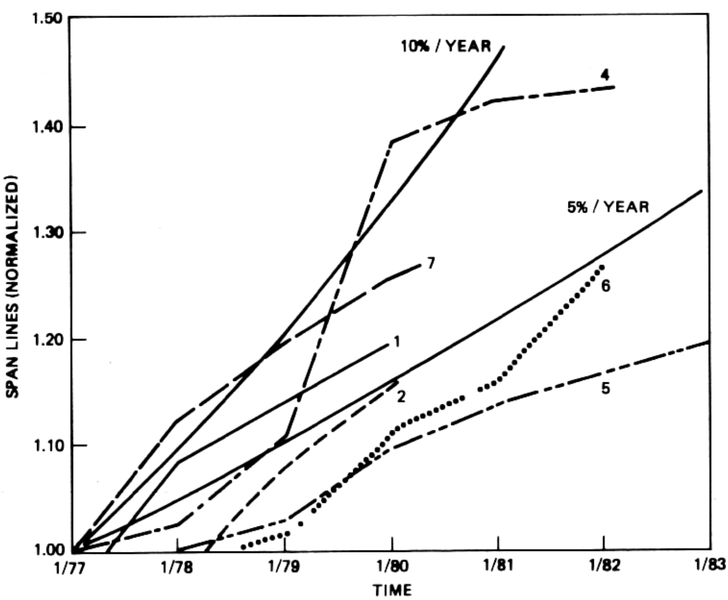


Fig. 25—Digital network growth on a span basis for six metropolitan areas.

the growth and its distribution is a valuable aid to study the applicability of new transmission systems. Usually in market studies, an estimate of the length and cross section of the span population, along with a predicted average growth rate applied to all spans, is used to predict the total network growth and potential applicability of individual facility types. Since both the actual distribution of average yearly growth and the distribution of cross section are known in this study, the validity of the method of growing all spans at the same rate can be evaluated.

The average growth rate of 6.0 percent was obtained by dividing the sum of the average yearly growth in DS1s of all spans by the total cross section of those spans as of January 1980, the middle of the growth projection period. Figure 26 shows the distribution of average yearly growth and the distribution predicted by applying the average growth rate of 6 percent to each cross section. The spans average a growth of 7.6 DS1s per year. About 8 percent of the spans are adding more than 24 span lines per year, and 32 percent are adding 1 span line or less. In fact, 21 percent of the spans are not growing or are turning down lines, in spite of averaging over the several year period. The predicted distribution differs from the actual distribution in that it underestimates the growth of the faster-growing spans (adding more than 15 DS1s) and overestimates the growth of the slower-growing spans. The predicted distribution does not show any spans adding

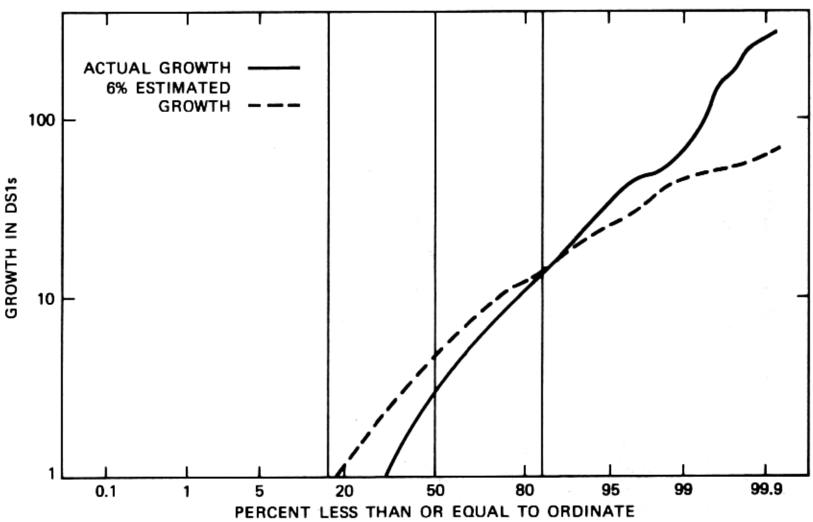


Fig. 26—Distribution of average yearly span growth in six metropolitan areas. Actual growth: average = 7.6; standard deviation = 18.5. Estimated growth of 6 percent: average = 7.6; standard deviation = 8.9.

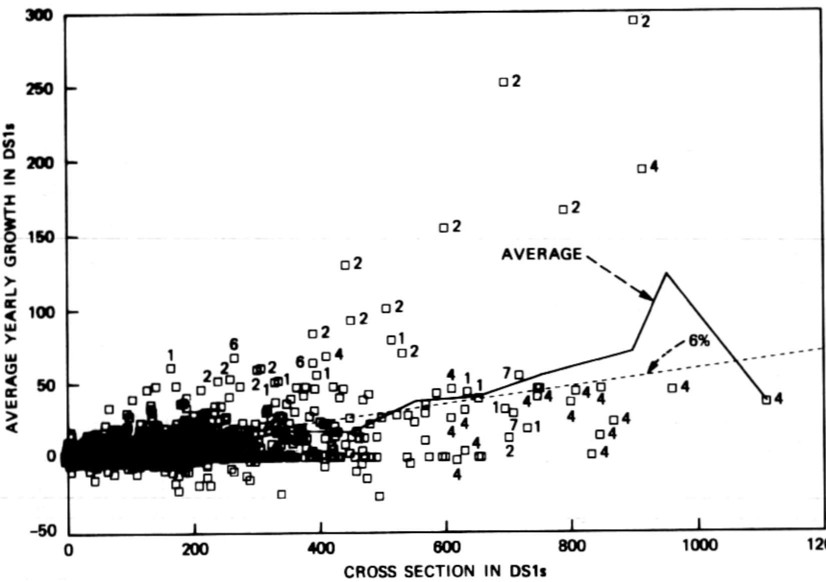


Fig. 27—Average yearly growth vs. working cross section in six metropolitan areas.

more than 65 DS1s per year, but growth projections indicate 12 such spans. One contribution to the difference between the actual distribution of projected growth and that predicted by applying the average network growth method to all spans is that the latter predicts positive growth for each span, whereas 21 percent of the spans have zero or negative growth. The concentration of growth in a small fraction of the spans is examined in Section 4.5.

4.3 Average yearly growth versus working cross section

Spans with large cross sections might be expected to add many DS1s each year. Hence, there may be a trend of increasing growth with increasing cross section. The relationship of average yearly growth to the January 1980 cross section is shown in Fig. 27. The overall average of 6 percent (indicated by the dashed line) is the ratio of the total average yearly growth to the total January 1980 cross section.

Three features are noteworthy. First, there is a trend of increasing average yearly growth with increasing cross section as indicated by the solid line, which is the average over 100 DS1 steps. Second, there is a wide variation of average yearly growth for a given cross section, including some negative values. Some spans have a net decrease in span lines over a period of 2 to 5 years. And third, area 2 has 14 spans of the 24 with average yearly growth greater than 50. These spans represent a major backbone route into the downtown metropolitan area.

4.4 Average yearly growth versus span length

Since downtown spans tend to be short, and suburban spans tend to be long, there may be a relationship of average yearly growth to span length. Figure 28 shows that this is not the case. There is no significant trend of average yearly growth with span length, as indicated by the solid line, which is the average over one-mile intervals up to 13 miles, with spans longer than 13 miles combined.

4.5 Span-line growth patterns

To understand the patterns of growth, the geographic location of high-growth spans was examined. All high-growth spans—those having average yearly growth greater than 50 DS1s—were found to be concentrated in the vicinity of No. 4 ESS digital switching machines. To quantitatively examine the extent to which T-carrier growth is influenced by No. 4 ESS switching machines, a No. 4 ESS span—or 4E span—is defined to be a span which has one of the following characteristics:

It is directly connected to a No. 4 ESS machine.

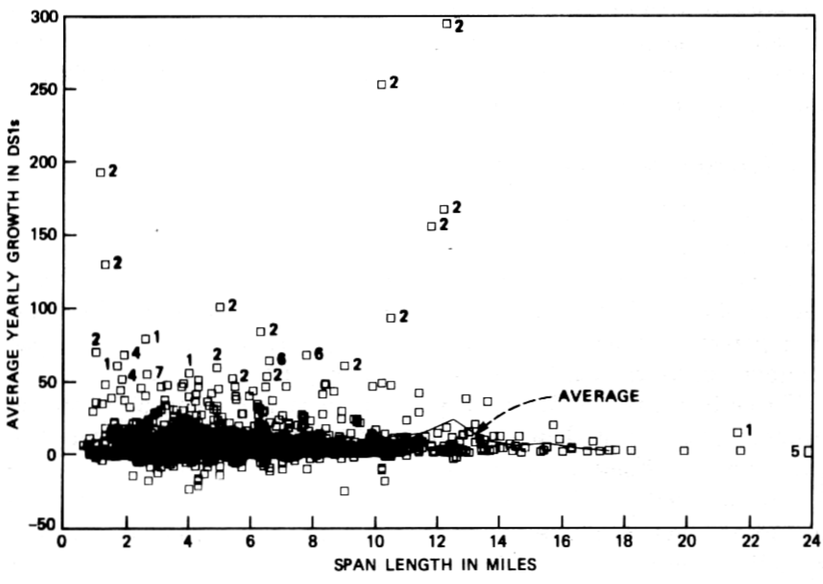


Fig. 28—Average yearly growth vs. span length in six metropolitan areas.

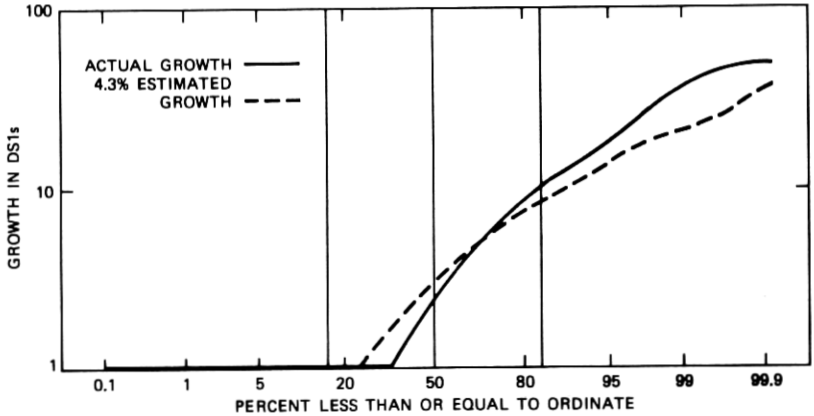


Fig. 29—Distribution of average yearly span growth in six metropolitan areas for 1151 non-4E spans. Actual growth: average = 4.4; standard deviation = 8.0. Estimated growth of 4.3 percent: average = 4.4; standard deviation = 4.6.

It is in a tandem path between two No. 4 ESSs.
It is part of a major backbone route to a No. 4 ESS.

Spans meeting one of these criteria usually have large cross sections. For example, Fig. 5 shows 66 spans with cross sections greater than 400 DS1s. Fifty-five of these high cross-section spans are 4E spans according to the above definition. Although these 4E spans were first identified by high growth, other spans which meet one of the three criteria have been included. A total of 88 spans in this study have been identified as 4E spans.

Since the 4E spans were first identified on the basis of large growth, examining growth for two separate populations, 4E and non-4E spans, may give insight into the growth pattern. Figure 29 shows the growth distribution for non-4E spans, together with the estimate based on growing all span cross sections at the average growth rate for non-4E spans of 4.3 percent. This estimate is a slightly better match than that of the total population in Fig. 26. However, the same discrepancies occur: underestimating the growth of the faster-growing spans and overestimating the growth of the slower-growing spans. The average non-4E span is adding 4.4 DS1s per year, about half of the 7.6 average for the total population, and no non-4E span is adding more than 48 DS1s per year.

Next, the population of the 88 4E spans is considered separately. The distribution of average yearly growth for the 4E spans, together with the estimate based on growing all 4E span cross sections at the 4E span average rate of 10.8 percent, are shown in Fig. 30. In this case, the estimate is a much better match to the actual data. In fact, this estimate is the closest obtained, mainly because none of the 4E spans have zero or negative average yearly growth. The average 4E span is adding 48 DS1s per year, about six times the total population average and 11 times the non-4E average.

Thus, the spans defined as 4E spans dominate the current T-carrier span line growth; Table I summarizes the characteristics of the 4E spans. Growth data are available for more than 1,200 spans. For the sum of all spans, the average growth rate is 6.0 percent. Although the 88 4E spans comprise only seven percent of the spans, they account for 25 percent of the total currently working cross section, and for 46 percent of the total average yearly growth.

This growth pattern is based on short-term current planning data. In the longer term, as No. 4 ESS machines become established, the growth on 4E spans may not be as dramatic, although some new 4E spans may be created that will grow rapidly. For the present network, however, this separation of spans into 4E and non-4E populations yields insight into the short-term growth behavior.

Another aspect of the growth is shown in the last two rows of this table. Based on the average yearly growth, there are 983 spans adding, and 256 spans losing, DS1s. The 79 percent of the spans gaining represent 86.8 percent of the total January 1980 cross section. Twenty-one percent of the spans have zero or negative average yearly growth in spite of averaging over several years. None of the 4E spans are losing lines, as indicated in Fig. 30.

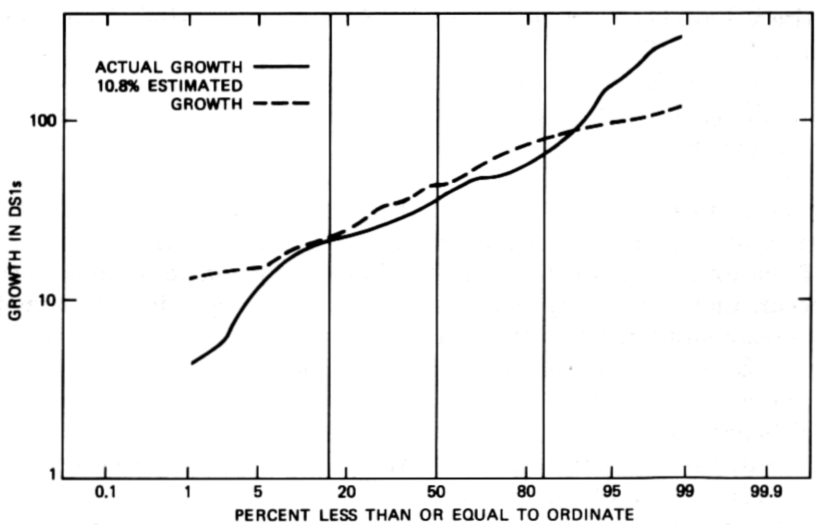


Fig. 30—Distribution of average yearly span growth in six metropolitan areas for 88 4E spans only. Actual growth: average = 48.4; standard deviation = 47.0. Estimated growth of 10.8 percent: average 48.4; standard deviation = 24.9.

Table I—Characteristics of the No. 4 ESS spans in the digital metropolitan network

Category	No. of Spans	Total Cross Section	Average Yearly Growth	Percent
Total	1,239	157,233	9,354	6.0 Growth
Not 4E	1,151	117,758	5,094	4.3 Growth
4E only	88	39,475	4,260	10.8 Growth
Gaining	983	136,499	10,039	86.8 Base
Losing	256	20,734	(−685)	13.2 Base

V. SUMMARY

The metropolitan digital trunk plant is estimated to contain from 5,000 to 6,000 spans providing approximately 160,000 T-carrier systems. Fundamental aspects of seven metropolitan areas, representing a 25-percent sample, have been presented and discussed. All areas are similar in span length distribution and have a 5.9-mile average and a 5.4-mile median. The average cross section is 137, with a median of 90 equivalent DS1 signals. One area has significantly higher cross sections generated by a natural geographic corridor of population.

On a span basis, an average of 41 percent of the ultimate engineering capacity of T-carrier in the present cable plant is used. Higher cross-section spans tend to have higher-percentage carrier fills.

Again, on a span basis, the use of apparatus-case slots averages 56 percent. Larger cross-section spans tend to have higher percentage apparatus-case fills.

The cables used for T1 cover a wide range of size and gauge, but the dominant type is single-cable operation on 900-pair, 22-gauge pulp. This 900-pair cable accounts for 39 percent of the cable mileage in the total sample, and as high as 63 percent in one area. However, recent and future installations are dominated by MAT or other screened cable.

Since the cable plant is mostly 22-gauge pulp, the average intermediate section length is 5.32 kft, which corresponds to a T1 insertion loss of 27.7 dB. Four percent of these sections use 19- or 22-gauge PIC and are longer than 6.3 kft. All sections have less than the 34-dB insertion loss allowed by T1 engineering rules.

The average end section is 2.86 kft, which corresponds to a T1 loss of 15.4 dB. Five percent of the end sections use 19- or 22-gauge PIC and exceed 4 kft. Except for the extremes of the distributions, all seven areas do not differ significantly in either the intermediate or end-section statistics.

The number of working span lines in the sample obtained is projected to grow at an average rate of six percent in the near future. The actual amount of growth varies somewhat from year to year in each area. Growth on individual spans varies considerably and is more concentrated in a small fraction of spans than is predicted on the basis of a constant percentage growth for all spans. Examining the geographic locations of the high-growth spans showed them to be associated with No. 4 ESS digital switching machines.