LONG TERM GROWTH TRENDS IN INTERNATIONAL TELECOMMUNICATIONS TRAFFIC: AN INTELSAT STUDY

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Abstract

Plans for the implementation of INTELSAT system capacity are developed in accordance with user-supplied, long-term traffic forecasts which are updated periodically. Taken collectively, these forecasts are referred to as the Integrated Traffic Data Base (ITDB). A study of the growth trends inherent in the ITDB projections have led to a simple statistical method for deriving upper and lower bounds for selected traffic streams, which, in turn, define a useful range of forecasts for performing sensitivity analyses of alternative future systems.

1. Introduction

This paper presents a description of recent work carried out within INTELSAT by way of analyzing growth trends in the long-term projections of user requirements. This work was initiated with the objective of investigating to what extent growth rate profiles, whether pertaining to the total requirements of a region or to an aggregation of select traffic paths, might lend themselves to statistical analyses. Two parameters are quantitatively determined by means of a least squares regression procedure. A third parameter is used as a measure of the dispersal of the projected growth rates around the time trend curve. Since a given profile of growth rates spans a forecast period of fifteen years, this approach accomplishes a five-fold reduction in the data required to characterize that profile.

What follows is a description of the ITDB along with a discussion of how it is assembled, a presentation of the statistical technique used to analyze growth trends within the ITDB while establishing bounds of variability, and an examination of how the technique is being applied to specific traffic aggregates in order to arrive at upper-bounds and lower-bounds for purposes of sensitivity analyses of satellite configurations expected to serve INTELSAT's future needs.

2. Integrated Traffic Data Base

The development of system plans for communications satellites carrying international service requires an estimate not only of volumes of circuit demand but also of the interconnectivity required to accommodate the large number of paths which constitute the global network. Furthermore, an international network connects countries with telecommunications infrastructures ranging from the most highly developed to the relatively undeveloped. INTELSAT studies have shown that it would be impracticable to recommend a forecasting method for general application by all users because of the wide diversity of needs in terms of types of service and growth rates.

The user community provides forecasts for determining assignments of available capacity to individual earth stations. Initially, forecasts were no more than agreed sets of guesses covering the immediate five year period. Gradually, such factors as the establishment of wideband communication facilities and the expansion of subscriber trunk dialling became better understood, and the forecasts are now assembled on the basis of established guidelines.

Within a short time, it was also realized that the demand for capacity was likely to remain very high for the foreseeable future. Satellite technology was developed rapidly, and the building of satellites with capacities of the order of several thousand circuits was perceived as practicable. However, the lead time for a satellite to be placed in orbit and ready for operation is six-to-eight years and, as the life expectancy of a satellite in orbit grew to more than five years, the need for long-term forecasts became imperative.

INTELSAT's response to these developments was a pragmatic one: the scheme of assembling the forecasts for five years was extended to fifteen years. This composite forecast, called the Integrated Traffic Data Base (ITDB), consists of a set of circuit forecasts provided by individual user-administrations either already operating or planning to operate within the INTELSAT network. These forecasts are compiled on a path-by-path and satellite-by-satellite basis according to category of services, i.e., voice, record (voice frequency telegraphy), alternate voice data, and data at both low and high transmission rates. Separate sections of the ITDB are maintained for the single-channel-per-carrier (SCPC), the companded FDM/FM (CFDM) and the combined FDM/FM and TDMA operating modes.
The fifteen-year period of the ITDB is thus subdivided into two parts, the first part being comprised of five-year (short-term) "agreed" circuit forecasts collected once a year at a specially-convened Global Traffic Meeting. The forecasts submitted are on the basis of bilateral agreements reached at the Meeting. The second part of the ITDB is comprised of the remaining ten-year (long-term) forecasts collected every two years and expressed either in terms of circuits or in terms of annual growth percentages. While bilateral agreement is considered desirable, it is not mandatory, and entries are made to the ITDB if either correspondent sees a service requirement.

This approach for compiling the ITDB leaves flexibility to the user-entities to develop forecasting techniques best suited to their own circumstances, but it does little to reduce the year-by-year variations and perturbations of demand assessment caused by differences in the bases of forecasting on a global scale. By way of providing an example of the resultant forecasts, Table 1 contains an excerpt from a recent ITDB relating to a particular country's links planned for operation in the Atlantic Ocean Region.

3. Long-Term Growth Trends

The pattern of growth in the ITDB forecasts for each bilateral relationship, and therefore for each ocean region, depends upon a large number of factors which vary in their relevance to the forecasts themselves. While the annual growth rates within a relationship could be governed by a set of particular circumstances, the requirements of the very many paths in a region are generally not always interdependent. For similar reasons, variability in the forecasts prepared in succeeding years also tends to mask the contributory factors. It is therefore considered useful to examine if the annual growth rates built into the demand estimates provided by the users and associated with a traffic profile could be represented by a simple time-trend curve. It was found that a time-trend curve could be selected requiring the specification of only two parameters and that a third parameter could then be derived to describe the dispersal of the forecast growth rates around the values established by the time-trend curve. Since the ITDB spans a period of fifteen years, this method accomplishes a five-for-one reduction in the data required to describe the pattern of growth in each link, or in a region containing an ensemble of links.

The curve used in this analytical treatment relates annual growth rates to time as follows:

\[ k_i = A e^{B_i} \]  

where "i" represents a given year within the ITDB time frame and where \( k_i \) is the growth rate estimate for year "i". The parameter "B" equals the instantaneous rate of growth or decay of the curve over the fifteen year period throughout the fifteen years. The curve is fitted to a given profile of growth rates by a least-squares regression after employing a logarithmic transformation so that equation (1) is thus expressed.

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Table 1: Format of I.T.D.B. Projection of Satellite Circuits on Some Atlantic Ocean Region Links

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is expressed as a straight line:

$$\log_{10} k_i = \log_{10} A + B_i$$

(2)

If \( r_i \) is taken to be the projected growth rate for year "i", then equation (2) may be rewritten as:

$$\log_{10} r_i = \log_{10} A + B_i + e$$

(3)

In the above equation \( e \) is the residual between \( \log_{10} r_i \) and the value estimated by equation (2). When expressed in exponential form, equation (3) becomes:

$$r_i = k_i e^e$$

(4)

Since the least-squares procedures requires that all \( e \)'s have a mean value of zero, and if the assumption is made that the \( e \)'s are randomly distributed about their mean value, equation (4) suggests that a range of dispersion may be defined in accordance with:

$$r_{i,\text{u}} = k_i e^\sigma$$

(5)

and

$$r_{i,\text{l}} = k_i e^{-\sigma}$$

(6)

where equation (5) and (6) are the respective upper limits and lower limits of the range and where \( \sigma \) is the standard deviation of the fifteen values of \( e \).

Figure 1 shows how equations (1), (5) and (6) are applied to the annual growth rate of a sample traffic stream. Four of the fifteen data points fall outside of the "one sigma" curves defined by equation (5) and (6), meaning that about 73% fall within. The value of \( \sigma \) for this case is 0.252 which yields an upper limit curve that is 28.7% above the time-trend curve throughout the forecast period. The lower limit curve is 22.3% below.

It is useful to examine the presumption that \( e \) is randomly distributed. For this purpose, this curve-fitting method was applied to a large aggregate of individual links in each of the three ocean regions. The results are summarized in Table 2. The residuals on each link were normalized by dividing each \( e \) by its corresponding \( \sigma \). The frequency distributions shown in Table 2 are of those normalized residuals. The three distributions are seen to be symmetrical and bell-shaped. In the remaining discussion of this paper \( e \) will be assumed to be normally distributed.

![Figure 1. Time-Trend Analysis of Annual Growth Rates for Sample Traffic Stream](image-url)
A Basis for Sensitivity Analyses

Using the results developed in the preceding section, it remains to establish a corresponding range of traffic profiles which can serve as a basis for evaluating prospective satellite designs and system configurations. Put simply, it is necessary to translate the range of growth rate profiles into a range of profiles representing compounded growth factors.

To accomplish this, a few definitions are in order: let $X_i$ equal $1+r_i$ (the growth rate factor for year $i$), let $E(X_i)$ equal the expected value of $X_i$, and let $V(X_i)$ equal the variance of $X_i$. Given that $\epsilon$ is normally distributed with zero mean and variance equal to $\sigma^2$, then:

$$E(X_i) = 1 + k_i \theta^{3/2}$$  \hspace{1cm} (7)

Equation (7) is derived from the fact that the random variable $X_i$ is distributed in accordance with the lognormal distribution. In addition, since:

$$V(X_i) = E(X_i)^2 - [E(X_i)]^2$$  \hspace{1cm} (8)

then:

$$V(X_i) = k_i^2 \theta^2 (\theta^2 - 1)$$  \hspace{1cm} (9)
The remainder of this discussion concentrates on the derivation of a closed-form expression for:

\[ E(X_1, X_2, \ldots, X_n) \triangleq \text{Expected value of the compounded growth rate factors for years, 1 through } n. \]

and

\[ V(X_1, X_2, \ldots, X_n) \triangleq \text{Variance of the compounded growth rate factors for years, } 1 \text{ through } n. \]

It is useful to first consider only two growth factors, \( X_1 \) and \( X_2 \). Since \( X_1 \) and \( X_2 \) are statistically independent:

\[ E(X_1, X_2) = E(X_1)E(X_2) \tag{10} \]

which, in turn, implies that:

\[ E(X_1, X_2, \ldots, X_n) = \prod_{i=1}^{n} \{E(X_i)\} \tag{11} \]

Next, it is observed that:

\[ V(X_1, X_2) = E(X_1^2) - [E(X_1)]^2 \tag{12} \]

which may be rewritten:

\[ V(X_1, X_2) = E(X_1^2)E(X_2)^2 - [E(X_1)]^2 [E(X_2)]^2 \tag{13} \]

where:

\[ E(X_1^2) \triangleq V(X_1) + [E(X_1)]^2 \tag{14} \]

and:

\[ E(X_2^2) \triangleq V(X_2) + [E(X_2)]^2 \tag{15} \]

The preceding expression may be set forth in the more general form:

\[ V(X_1, X_2, \ldots, X_n) = \prod_{i=1}^{n} \{E(X_i^2)\} - \prod_{i=1}^{n} \{[E(X_i)]^2\} \tag{16} \]

where:

\[ E(X_1^2) = V(X_1) + [E(X_1)]^2 \tag{17} \]

By making the appropriate substitutions from equations (7) and (9), equation (11) becomes:

\[ E(X_1, X_2, \ldots, X_n) = \prod_{i=1}^{n} \{1 + k_i e^{\sigma^2/2} + k_i^2 e^{\sigma^2/2} \} \tag{18} \]

and equation (17) becomes:

\[ E(X_1^2) = 1 + 2k_1 e^{\sigma^2/2} + k_1^2 e^{\sigma^2} \tag{19} \]

Finally, the above result may be combined with equation (16) to give:

\[ V(X_1, X_2, \ldots, X_n) = \prod_{i=1}^{n} \{1 + 2k_i e^{\sigma^2/2} + k_i^2 e^{\sigma^2} \} \tag{20} \]

Equation (18) is the expected value of the compounded growth factor profile at year "n". Upper and lower bounds are obtained by respectively adding to and subtracting from the profile value determined by equation (18) the square root of the value determined by equation (20).

5. Application of the Method

The analytical method described in this paper defines a set of growth-factor trend curves the characteristics of which are built into the traffic contributions made to the ITDB by the user community. The limits of statistical variability derived from this trend analysis may therefore be interpreted as an indicator of the impact of a number of mutually independent factors upon the realization of traffic.

To illustrate the method by applying it to an actual forecast, the aggregate projection of FDM/FM half-circuits in the Pacific Ocean Region was selected from the 1982 ITDB. Equations (1), (5) and (6) were then applied to the associated annual growth rates. The outcome is summarized in Table 3. In this example, \( \sigma \) was computed to be 0.14297. Table 4 shows the corresponding forecasts in terms of numbers of telephone channels.

Figure 2 is an ensemble of plots for the three ocean regions. Each of the plots shows the range of variations that may be statistically associated with the forecasts for 1990 as specified in the ITDB's generated during the year, 1977 through 1982. For each year, four points are plotted, representing the trend

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<th>TIME-TREND</th>
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* Bounded to nearest integer percentage.
value, the upper and lower bounds and the forecast value in the ITDB, respectively.

INTELSAT's long-term forecast data base is only five years old, and although it is too early to set firm upper and lower bounds within which successive years' forecasts may be expected to remain, the developments in the Atlantic and the Indian Ocean Regions suggest a see-saw pattern which may perhaps eventually define a broad range of variability. For the present, since nearly half the forecasts over successive years (Table 5) fall within a range of plus 15% or minus 10% of the trend based values, these upper and lower bounds could serve as initial benchmarks for sensitivity analyses. A trend analysis of the forecasts assembled each year will continue to be used for reviewing these limits.

### Table 4 Year-End Traffic Projections in the Pacific Ocean Region (PDM/PM Half-Circuits)

<table>
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<th>YEAR</th>
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<td>1996</td>
<td>61.064</td>
<td>61.302</td>
<td>66.320</td>
<td>56.290</td>
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* Actual traffic carried.

### Figures

**Figure 2.** Comparison between I.T.D.B. and Trend Model Forecasts for End-Year 1990

- Atlantic Ocean Region
- Indian Ocean Region
- Pacific Ocean Region

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TABLE 5  VARIATIONS RELATIVE TO I.T.D.B. FORECASTS

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6. References
