1

Traffic System Design Overview

Traffic system design is a process that considers the entire telecommunication system and the interrelationship of its components. Total system and subsystem performance (i.e., service) objectives are specified, and conflicts are resolved to achieve an optimum configuration. Therefore, traffic system design ensures the cost-effective dimensioning of switching and transmission equipment (traffic-handling resources or servers) to provide the required service objectives (grade of service) economically. Telephone traffic (teletraffic) theory—drawing on many disciplines including electronics, mathematics, statistics, probability, queuing theory, reliability, and economics—is at the heart of traffic system design.

1.1 TRAFFIC UNITS

Traffic units are a measure of traffic intensity, the average traffic density during a one-hour period. The international unit of traffic intensity is the Erlang,* where one Erlang represents a circuit occupied for one hour.

* Named for A.K. Erlang, the father of telephone traffic theory [Brockmeyer, 1948].

The Erlang defines the efficiency (percent occupancy) of a traffic resource and represents the total time in hours to carry all calls. It is the traffic unit used exclusively in classic traffic theory.

In the North American public switched telephone network (PSTN), the standard traffic unit is the unit call (UC), which is expressed in seconds. The UC is defined in centum-call-seconds (CCS) or more commonly, hundred-call-seconds. Equation 1.1 gives the relationship between Erlangs and CCS. Table 1-1 is an Erlang-to-CCS conversion chart for selected traffic levels up to 200 Erlangs (7200 CCS).

$$1 \text{ Erlang} = 1 \text{ call-hour} = 3600 \text{ call-seconds} = 36 \text{ CCS} \qquad (1.1)$$

1.2 TRAFFIC CALCULATIONS

Before common-equipment pools such as trunk groups, signaling registers, and operator positions can be dimensioned, their busy-hour traffic intensities must be determined. Trunks are assigned to serve calls on an immediate basis and are held for the duration of the call. Signaling registers, operator positions, and similar servers normally serve calls on a delayed basis and are held only long enough to serve their specific functions.

1.2.1 Trunk-Group Traffic

Routing plans specify a mix of direct-route and alternate-route trunk groups to provide least-cost routing of interswitch traffic through the network. The selected routing technique determines, to some extent, the level of traffic offered to each trunk group. Offered trunk-group traffic is the total of all traffic offered to the group. If the trunk group were large enough, it would carry all offered traffic but such a trunk group probably would not be economical. Instead, trunk groups are engineered to block a fraction of the offered busy-hour traffic, typically one to ten percent.

Table 1-1. Traffic-Unit Conversion Chart

Erlangs	CCS	Erlangs	CCS	Erlangs	CCS	Erlangs	CCS	Erlangs	CCS
0.05	1.8	2.05	73.8	4.05	145.8	6.05	217.8	8.05	289.8
0.10	3.6	2.10	75.6	4.10	147.6	6.10	219.6	8.10	291.6
0.15	5.4	2.15	77.4	4.15	149.4	6.15	221.4	8.15	293.4
0.20	7.2	2.20	79.2	4.20	151.2	6.20	223.2	8.20	295.2
0.25	9.0	2.25	81.0	4.25	153.0	6.25	225.0	8.25	297.0
0.30	10.8	2.30	82.8	4.30	154.8	6.30	226.8	8.30	298.8
0.35	12.6	2.35	84.6	4.35	156.6	6.35	228.6	8.35	300.6
0.40	14.4	2.40	86.4	4.40	158.4	6.40	230.4	8.40	302.4
0.45	16.2	2.45	88.2	4.45	160.2	6.45	232.2	8.45	304.2
0.50	18.0	2.50	90.0	4.50	162.0	6.50	234.0	8.50	306.0
0.55	19.8	2.55	91.8	4.55	163.8	6.55	235.8	8.55	307.8
0.60	21.6	2.60	93.6	4.60	165.6	6.60	237.6	8.60	309.6
0.65	23.4	2.65	95.4	4.65	167.4	6.65	239.4	8.65	311.4
0.70	25.2	2.70	97.2	4.70	169.2	6.70	241.2	8.70	313.2
0.75	27.0	2.75	99.0	4.75	171.0	6.75	243.0	8.75	315.0
0.80	29.8	2.80	100.8	4.80	172.8	6.80	244.8	8.80	316.8
0.85	30.6	2.85	102.6	4.85	174.6	6.85	246.6	8.85	318.6
0.90	32.4	2.90	104.4	4.90	176.4	6.90	248.4	8.90	320.4
0.95	34.2	2.95	106.2	4.95	178.2	6.95	250.2	8.95	322.2
1.00	36.0	3.00	108.0	5.00	180.0	7.00	252.0	9.00	324.0
1.05	37.8	3.05	109.8	5.05	181.8	7.05	253.9	9.05	325.8
1.10	39.6	3.10	111.6	5.10	183.6	7.10	255.6	9.10	327.6
1.15	41.4	3.15	113.4	5.15	185.4	7.15	257.4	9.15	329.4
1.20	43.2	3.20	115.2	5.20	187.2	7.20	259.2	9.20	331.2
1.25	45.0	3.25	117.0	5.25	189.0	7.25	261.0	9.25	333.0
1.30	46.8	3.30	118.8	5.30	190.8	7.30	262.8	9.30	334.8
1.35	48.6	3.35	120.6	5.35	192.6	7.35	264.6	9.35	336.6
1.40	50.4	3.40	122.4	5.40	194.4	7.40	266.4	9.40	338.4
1.45	52.2	3.45	124.2	5.45	196.2	7.45	268.2	9.45	340.2
1.50	54.0	3.50	126.0	5.50	198.0	7.50	270.0	9.50	342.0
1.55	55.8	3.55	127.8	5.55	199.8	7.55	271.8	9.55	343.8
1.60	57.6	3.60	129.6	5.60	201.6	7.60	273.6	9.60	345.6
1.65	59.4	3.65	131.4	5.65	203.4	7.65	275.4	9.65	347.4
1.70	61.2	3.70	133.2	5.70	205.2	7.70	277.2	9.70	349.2
1.75	63.0	3.75	135.0	5.75	207.0	7.75	279.0	9.75	351.0
1.80	64.8	3.80	136.8	5.80	208.8	7.80	280.8	9.80	352.8
1.85	66.6	3.85	138.6	5.85	210.6	7.85	282.6	9.85	354.6
1.90	68.4	3.90	140.4	5.90	212.4	7.90	284.4	9.90	356.4
1.95	70.2	3.95	142.2	5.95	214.2	7.95	285.2	9.95	358.2
2.00	72.0	4.00	144.0	6.00	216.0	8.00	288.0	10.00	360.0

(*table continues*)

Table 1-1. Traffic-Unit Conversion Chart (*Continued*)

Erlangs	CCS	Erlangs	CCS	Erlangs	CCS	Erlangs	CCS	Erlangs	CCS
10.1	363.6	14.1	507.6	18.1	651.6	22.1	795.6	26.1	939.6
10.2	367.2	14.2	511.2	18.2	654.2	22.2	799.2	26.2	943.2
10.3	370.8	14.3	514.8	18.3	658.8	22.3	802.8	26.3	946.8
10.4	374.4	14.4	518.4	18.4	662.4	22.4	806.4	26.4	950.4
10.5	378.0	14.5	522.0	18.5	666.0	22.5	810.0	26.5	954.0
10.6	381.6	14.6	525.6	18.6	669.6	22.6	813.6	26.6	957.6
10.7	385.2	14.7	529.2	18.7	673.2	22.7	817.2	26.7	961.2
10.8	388.8	14.8	532.8	18.8	676.8	22.8	820.8	26.8	964.8
10.9	392.4	14.9	536.4	18.9	680.4	22.9	824.4	26.9	968.4
11.0	396.0	15.0	540.0	19.0	684.0	23.0	828.0	27.0	972.0
11.1	399.6	15.1	543.6	19.1	687.6	23.1	831.6	27.1	975.6
11.2	403.2	15.2	547.2	19.2	691.2	23.2	835.2	27.2	979.2
11.3	406.8	15.3	550.8	19.3	694.8	23.3	838.8	27.3	982.8
11.4	410.4	15.4	554.4	19.4	698.4	23.4	842.4	27.4	986.4
11.5	414.0	15.5	558.0	19.5	702.0	23.5	846.0	27.5	990.0
11.6	417.6	15.6	561.6	19.6	705.6	23.6	849.6	27.6	993.6
11.7	421.2	15.7	565.2	19.7	709.2	23.7	853.2	27.7	997.2
11.8	424.8	15.8	568.8	19.8	712.8	23.8	856.8	27.8	1000.8
11.9	428.4	15.9	572.4	19.9	716.2	23.9	860.2	27.9	1004.2
12.0	432.0	16.0	576.0	20.0	720.0	24.0	864.0	28.0	1008.0
12.1	431.6	16.1	579.6	20.1	723.6	24.1	867.6	28.1	1011.6
12.2	439.2	16.2	583.2	20.2	727.2	24.2	871.2	28.2	1015.2
12.3	442.8	16.3	586.8	20.3	730.8	24.3	874.8	28.3	1018.8
12.4	446.4	16.4	590.4	20.4	734.4	24.4	878.4	28.4	1022.4
12.5	450.0	16.5	594.0	20.5	738.0	24.5	882.0	28.5	1026.0
12.6	453.6	16.6	597.6	20.6	741.6	24.6	885.6	28.6	1029.6
12.7	457.2	16.7	601.2	20.7	745.2	24.7	889.2	28.7	1033.2
12.8	460.8	16.8	604.8	20.8	748.8	24.8	892.8	28.8	1036.8
12.9	464.4	16.9	608.4	20.9	752.4	24.9	896.4	28.9	1040.4
13.0	468.0	17.0	612.0	21.0	756.0	25.0	900.0	29.0	1044.0
13.1	471.6	17.1	615.6	21.1	759.6	25.1	903.6	29.1	1047.6
13.2	475.2	17.2	619.2	21.2	763.2	25.2	907.2	29.2	1051.2
13.3	478.8	17.3	622.8	21.3	766.8	25.3	910.8	29.3	1054.8
13.4	482.4	17.4	626.4	21.4	770.4	25.4	914.4	29.4	1058.4
13.5	486.0	17.5	630.0	21.5	774.0	25.5	918.0	29.5	1062.0
13.6	489.6	17.6	633.6	21.6	777.6	25.6	921.6	29.6	1065.6
13.7	493.2	17.7	637.2	21.7	781.2	25.7	925.2	29.7	1069.2
13.8	496.8	17.8	640.8	21.8	784.8	25.8	928.8	29.8	1072.8
13.9	500.4	17.9	644.4	21.9	788.4	25.9	932.4	29.9	1076.2
14.0	504.0	18.0	648.0	22.0	792.0	26.0	936.0	30.0	1080.0

(*table continues*)

Table 1-1. Traffic-Unit Conversion Chart (*Continued*)

Erlangs	CCS	Erlangs	CCS	Erlangs	CCS	Erlangs	CCS	Erlangs	CCS
30.1	1083.6	34.1	1227.6	38.1	1371.6	42.1	1515.6	46.1	1659.6
30.2	1087.2	34.2	1231.2	38.2	1375.2	42.2	1519.2	46.2	1663.2
30.3	1090.8	34.3	1234.8	38.3	1378.8	42.3	1522.8	46.3	1666.8
30.4	1094.2	34.4	1238.4	38.4	1382.4	42.4	1526.4	46.7	1670.4
30.5	1098.0	34.5	1242.0	38.5	1386.0	42.5	1530.0	46.5	1674.0
30.6	1101.6	34.6	1245.6	38.6	1389.6	42.6	1533.6	46.6	1677.6
30.7	1105.2	34.7	1249.2	38.7	1393.2	42.7	1537.2	46.7	1681.2
30.8	1108.8	34.8	1252.8	38.8	1396.8	42.8	1540.8	46.8	1684.8
30.9	1112.4	34.9	1256.4	38.9	1400.4	42.9	1544.4	46.9	1688.4
31.0	1116.0	35.0	1260.0	39.0	1404.0	43.0	1548.0	47.0	1692.0
31.1	1119.6	35.1	1263.6	39.1	1407.6	43.1	1551.6	47.1	1695.6
31.2	1123.2	35.2	1267.2	39.2	1411.2	43.2	1555.2	47.2	1699.2
31.3	1126.8	35.3	1270.8	39.3	1414.8	43.3	1558.8	47.3	1702.8
31.4	1130.4	35.4	1274.4	39.4	1418.4	43.4	1562.4	47.4	1706.4
31.5	1134.0	35.5	1278.0	39.5	1422.0	43.5	1566.0	47.5	1710.0
31.6	1137.6	35.6	1281.6	39.6	1425.6	43.6	1569.6	47.6	1713.6
31.7	1141.2	35.7	1285.2	39.7	1429.2	43.7	1573.2	47.7	1717.4
31.8	1144.8	35.8	1288.8	39.8	1432.8	43.8	1576.8	47.8	1720.8
31.9	1148.4	35.9	1292.4	39.9	1436.4	43.9	1580.4	47.9	1724.4
32.0	1152.0	36.0	1296.0	40.0	1440.0	44.0	1584.0	48.0	1728.0
32.1	1155.6	36.1	1299.6	40.1	1443.6	44.1	1587.6	48.1	1731.6
32.2	1159.2	36.2	1303.2	40.2	1447.2	44.2	1591.2	48.2	1735.2
32.3	1162.8	36.3	1306.8	40.3	1450.8	44.3	1594.8	48.3	1738.8
32.4	1166.4	36.4	1310.4	40.4	1454.4	44.4	1598.4	48.4	1742.4
32.5	1170.0	36.5	1314.0	40.5	1458.0	44.5	1602.0	48.5	1746.0
32.6	1173.6	36.6	1317.6	40.6	1461.6	44.6	1605.6	48.6	1749.6
32.7	1177.2	36.7	1321.2	40.7	1465.2	44.7	1609.2	48.7	1753.2
32.8	1180.8	36.8	1324.8	40.8	1468.8	44.8	1612.8	48.8	1756.8
32.9	1184.4	36.9	1328.4	40.9	1472.4	44.9	1616.4	48.9	1760.4
33.0	1188.0	37.0	1332.0	41.0	1476.0	45.0	1620.0	49.0	1764.0
33.1	1191.6	37.1	1335.6	41.1	1479.6	45.1	1623.6	49.1	1767.6
33.2	1195.2	37.2	1339.2	41.2	1483.2	45.2	1627.2	49.2	1771.2
33.3	1198.8	37.3	1342.8	41.3	1486.8	45.3	1630.8	49.3	1774.8
33.4	1202.4	37.4	1346.4	41.4	1490.4	45.4	1634.4	49.4	1778.4
33.5	1206.0	37.5	1350.0	41.5	1494.0	45.5	1638.0	49.5	1782.0
33.6	1209.6	37.6	1353.6	41.6	1497.6	45.6	1641.6	49.6	1785.6
33.7	1213.2	37.7	1357.2	41.7	1501.2	45.7	1645.2	49.7	1789.2
33.8	1216.8	37.8	1360.8	41.8	1504.8	45.8	1648.8	49.8	1792.8
33.9	1220.4	37.9	1364.4	41.9	1508.4	45.9	1652.4	49.9	1796.4
34.0	1224.0	38.0	1368.0	42.0	1512.0	46.0	1656.0	50.0	1800.0

(*table continues*)

Table 1-1. Traffic-Unit Conversion Chart (*Continued*)

Erlangs	CCS	Erlangs	CCS	Erlangs	CCS	Erlangs	CCS	Erlangs	CCS
50.5	1818	70.5	2538	90.5	3258	121.0	4356	161.0	5796
51.0	1836	71.0	2556	91.0	3276	122.0	4392	162.0	5832
51.5	1854	71.5	2574	91.5	3294	123.0	4428	163.0	5868
52.0	1872	72.0	2592	92.0	3312	124.0	4464	164.0	5904
52.5	1890	72.5	2610	92.5	3330	125.0	4500	165.0	5940
53.0	1908	73.0	2628	93.0	3348	126.0	4536	166.0	5976
53.5	1926	73.5	2646	93.5	3366	127.0	4572	167.0	6012
54.0	1944	74.0	2664	94.0	3384	128.0	4608	168.0	6048
54.5	1962	74.5	2682	94.5	3402	129.0	4644	169.0	6084
55.0	1980	75.0	2700	95.0	3420	130.0	4680	170.0	6120
55.5	1998	75.5	2718	95.5	3438	131.0	4716	171.0	6156
56.0	2016	76.0	2736	96.0	3456	132.0	4752	172.0	6192
56.5	2034	76.5	2754	96.5	3474	133.0	4788	173.0	6228
57.0	2052	77.0	2772	97.0	3492	134.0	4824	174.0	6264
57.5	2070	77.5	2790	97.5	3510	135.0	4860	175.0	6300
58.0	2088	78.0	2808	98.0	3528	136.0	4896	176.0	6336
58.5	2106	78.5	2826	98.5	3546	137.0	4932	177.0	6372
59.0	2124	79.0	2844	99.0	3564	138.0	4968	178.0	6408
59.5	2142	79.5	2862	99.5	3582	139.0	5004	179.0	6444
60.0	2160	80.0	2880	100.0	3600	140.0	5040	180.0	6480
60.5	2178	80.5	2898	101.0	3636	141.0	5076	181.0	6516
61.0	2196	81.0	2916	102.0	3672	142.0	5112	182.0	6552
61.5	2214	81.5	2934	103.0	3708	143.0	5148	183.0	6588
62.0	2232	82.0	2952	104.0	3744	144.0	5184	184.0	6624
62.5	2250	82.5	2970	105.0	3780	145.0	5220	185.0	6660
63.0	2268	83.0	2988	106.0	3816	146.0	5256	186.0	6696
63.5	2286	83.5	3006	107.0	3852	147.0	5292	187.0	6732
64.0	2304	84.0	3024	108.0	3888	148.0	5328	188.0	6768
64.5	2322	84.5	3042	109.0	3924	149.0	5364	189.0	6804
65.0	2340	85.0	3060	110.0	3960	150.0	5400	190.0	6840
65.5	2358	85.5	3078	111.0	3996	151.0	5436	191.0	6876
66.0	2376	86.0	3096	112.0	4032	152.0	5472	192.0	6912
66.5	2394	86.5	3114	113.0	4068	153.0	5508	193.0	6948
67.0	2412	87.0	3132	114.0	4104	154.0	5544	194.0	6984
67.5	2430	87.5	3150	115.0	4140	155.0	5580	195.0	7020
68.0	2448	88.0	3168	116.0	4176	156.0	5616	196.0	7056
68.5	2466	88.5	3186	117.0	4212	157.0	5652	197.0	7092
69.0	2484	89.0	3204	118.0	4248	158.0	5688	198.0	7128
69.5	2502	89.5	3222	119.0	4284	159.0	5724	199.0	7164
70.0	2520	90.0	3240	120.0	4320	160.0	5760	200.0	7200

Figure 1-1 can be used to facilitate an understanding of traffic routing terms. Interswitch traffic is routed over the primary route trunk group provided there are idle trunks available in the group. In an alternate-routing system, blocked trunk-group traffic overflows to other alternate-route trunk groups or to final-route trunk groups as indicated by the curved arrows. Trunk groups provided with alternate routes are often referred to as *high-usage trunk groups*. Final-route trunk groups do not have alternate routes; therefore, blocked traffic in a final-route trunk group is lost.

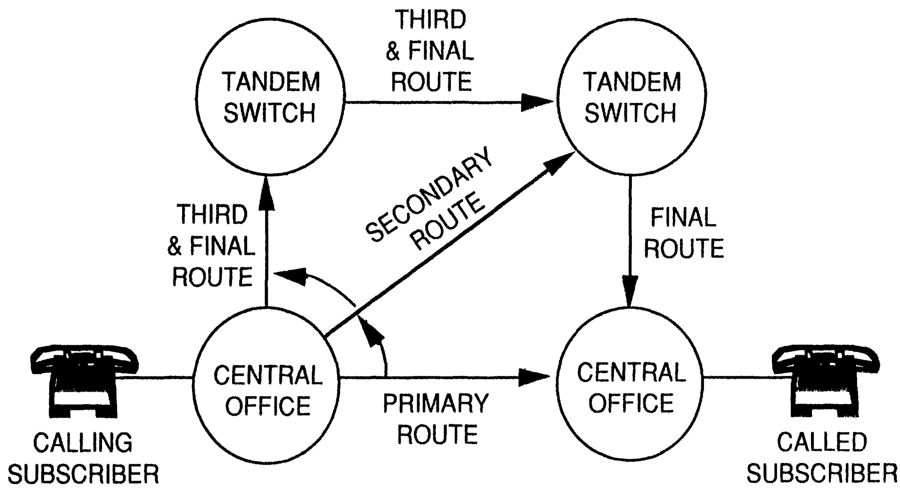

Figure 1-1. Interswitch Trunk Traffic Routing Diagram

Trunk-group traffic is the product of the number and duration of calls handled by the group. Equation 1.2 can be used to calculate trunk-group traffic, expressed in Erlangs.

$$A = N \bullet T_c \qquad (1.2)$$

where A = Offered traffic in Erlangs
N = Number of calls during the busy hour
T_c = Mean call-holding time in hours

Number of calls refers to the total number of calls offered to the trunk group. Call-holding time is the total elapsed time between seizure of a trunk to serve the call and its subsequent release. The mean call-holding time is the arithmetic average of all call-holding times, expressed in hours.

Example 1-1

Determine the traffic in Erlangs and CCS for a trunk group carrying 1000 calls during the busy hour with an average call-holding time of 3 minutes.

A = (1000 calls/hour)(3 min/call)(1 hour/60 min) = 50 Erlangs
(50 Erl)(36 CCS/Erl) = 1800 CCS

1.2.2 Server-Pool Traffic

Server pools are groups of traffic resources, such as signaling registers and operator positions, that are used on a shared basis. Service requests that cannot be met immediately are placed in a queue and served on a first-in, first-out (FIFO) basis. Server-pool traffic is directly related to offered traffic, server-holding time, and call-attempt factor, and inversely related to call-holding time as expressed in Equation 1.3.

$$A_S = \frac{A_T \bullet T_S \bullet C}{T_C} \tag{1.3}$$

where A_S = Server-pool traffic in Erlangs
A_T = Total traffic served in Erlangs
T_S = Mean server-holding time in hours
T_C = Mean call-holding time in hours
C = Call-attempt factor (dimensionless)

Total traffic served refers to the total offered traffic that requires the services of the specific server pool for some portion of the call. For example, a dual-tone multifrequency (DTMF) receiver pool is dimensioned to serve only the DTMF tone-dialing portion of total switch traffic generated by DTMF signaling sources. Table 1-2 presents representative server-holding times for typical signaling registers as a function of the number of digits received or sent.

Table 1-2. Typical Signaling Register Holding Times in Seconds

Signaling Register	Number of Digits Received or Sent				
	1	4	7	10	11
Local Dial-Pulse (DP) Receiver	3.7	8.3	12.8	17.6	19.1
Local DTMF Receiver	2.3	5.2	8.1	11.0	12.0
Incoming MF Receiver	1.0	1.4	1.8	2.2	2.3
Outgoing MF Sender	1.5	1.9	2.3	2.8	3.0

The mean server-holding time is the arithmetic average of all server-holding times for the specific server pool. Equation 1.4 is a general equation to calculate mean server-holding time for calls with different holding-time characteristics.

$$T_S = a \cdot T_1 + b \cdot T_2 + \cdots + k \cdot T_n \tag{1.4}$$

where T_S = Mean server-holding time in hours
$T_1, T_2, \cdots, T_n$ = Individual server-holding times in hours
$a, b, \cdots, k$ = Fractions of total traffic served ($a + b + \cdots + k = 1$)

Example 1-2

Determine the mean DTMF receiver-holding time for a central office (CO) where subscribers dial local calls using a 7-digit number and toll calls using an 11-digit number. Assume that 70 percent of the calls are local calls, the remainder are toll calls, and that the typical signaling register holding times of Table 1-2 are applicable.

$$T_S = (0.7)(8.1 \text{ sec}) + (0.3)(12.0 \text{ sec}) = 9.27 \text{ sec}$$

Call-attempt factors are dimensionless numbers that adjust offered traffic intensity to compensate for call attempts that do not result in completed calls. Therefore, call-attempt factors are inversely proportional to the fraction of completed calls as defined in Equation 1.5.

$$C = \frac{1}{k} \tag{1.5}$$

where C = Call-attempt factor (dimensionless)
k = Fraction of calls completed (decimal fraction)

Example 1-3

Table 1-3 presents representative subscriber call-attempt dispositions based on empirical data amassed in the North American PSTN. Determine the call-attempt factor for these data, where 70.7 percent of the calls were completed ($k = 0.707$).

$$C = \frac{1}{k} = \frac{1}{0.707} = 1.414$$

Table 1-3. Typical Call-Attempt Dispositions

Call-Attempt Disposition	Percentage
Call was completed	70.7
Called subscriber did not answer	12.7
Called subscriber line was busy	10.1
Call abandoned without system response	2.6
Equipment blockage or failure	1.9
Customer dialing error	1.6
Called directory number changed or disconnected	0.4

Example 1-4

Using Equation 1.3, determine the server-pool traffic in CCS and Erlangs for the DTMF receivers of Example 1-2, assuming total offered busy-hour subscriber traffic of 2000 CCS, a call-attempt factor of 1.5, and a mean call-holding time of 3 minutes (180 seconds).

$$A_S = (2000\ \text{CCS})\ (1.5)\frac{(9.27\ \text{sec})}{(180\ \text{sec})} = 154.5\ \text{CCS}$$

$$(154.5\ \text{CCS})\ \frac{(1\ \text{Erl})}{(36\ \text{CCS})} = 4.29\ \text{Erlangs}$$

1.3 TRAFFIC ASSUMPTIONS

Traffic formulas are based on a set of assumptions regarding the behavior of traffic and its sources. These assumptions are not always precisely true. If variations from these assumptions are small or known to have little effect, however, they can be used with confidence.

1.3.1 General Assumptions

The following assumptions are applicable to traffic formulas in general:

- The system is in statistical equilibrium.
- Connection and disconnection of sources to servers occur instantaneously.
- The anticipated traffic density is the same for all sources.
- Busy sources initiate no calls.
- Every source has equal access to every server (full availability).

- The number of busy servers in a group is equal to the number of busy sources in its group of sources.

1.3.2 Number of Sources

The number of sources that can originate calls affects the service these sources can expect to obtain. As the number of sources increases, the effect of adding more sources diminishes. Eventually, a point is reached where there is negligible difference in the probability of congestion regardless of how many new sources are added. It is this point that distinguishes between finite and infinite sources. Traffic formulas for applications where the number of sources in relation to the number of servers is very large assume infinite sources (worst case for blocking). This simplifies the mathematics and minimizes the number of required tables.

1.3.3 Disposition of Blocked Calls

Many assumptions for the disposition of blocked calls (which are also referred to as *lost calls*) have been proposed, of which the three common cases are:

- If an idle server is not immediately available, the call is cleared from the system and the source becomes idle. This is commonly called the *blocked calls cleared assumption.*
- If an idle server is not immediately available, the call is held for an interval equal to its holding time, and then the source becomes idle. If an idle server becomes available during the waiting period, it will be seized and held for an interval equal to the remaining portion of its mean holding time. This is commonly called the *blocked calls held assumption.*
- If an idle server is not immediately available, the call is queued until an idle server is available. When an idle server becomes available, it will be seized to serve the next call in queue and held for the full call-holding time. This is commonly called the *blocked calls delayed assumption.*

1.3.4 Holding-Time Distributions

A negative-exponential curve usually provides a reasonable fit for the variation in holding times encountered with nondelayed traffic-handling resources. Substituting a constant holding time equal to the average of varying holding times has a negligible effect for these applications. The effects of holding-time variations may be significant, however, when predicting the duration of delays. For example, the Crommelin-Pollaczek formulas are often used to determine service delays for resources with essentially constant holding times, such as dial-tone markers and intertoll trunks. Molnar's *Delay Probability Charts for Telephone Traffic Where the Holding Times Are Constant* graphically present data for these and similar applications.

1.4 GRADE OF SERVICE

Grade of service (GOS) is defined as the probability that offered traffic will be blocked or delayed. An absolutely nonblocking system has a GOS of zero, whereas a GOS of one indicates an absolutely blocking system. That is, the closer the grade of service is to zero, the better the system.

Every traffic problem involves three interrelated parameters: offered traffic, traffic-handling resources (servers), and service objective (grade of service). This interrelationship can be pictured as a triangle, as shown in Fig. 1-2. For a given service objective (base of triangle held constant), increasing offered traffic requires a commensurate increase in the number of servers. Similarly, decreasing the number of servers requires a corresponding decrease in the level of offered traffic.

It is important to understand that a server's GOS is a prediction of the probability of congestion (i.e., a call is blocked or delayed) at a given level of

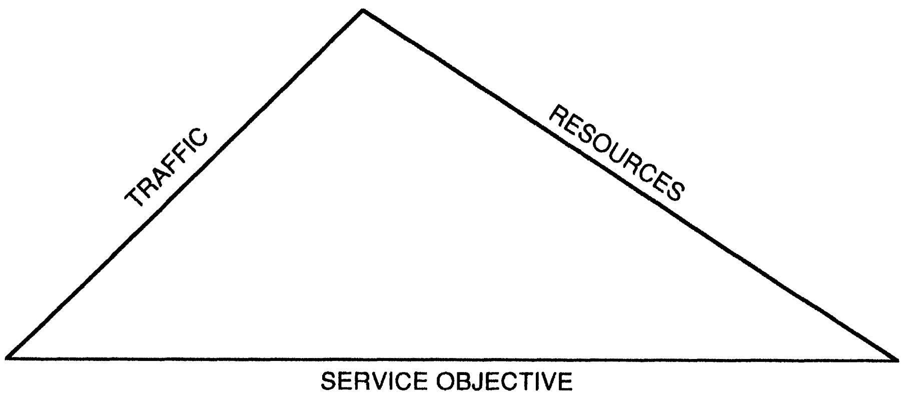

Figure 1-2. Grade of Service Concept Diagram

offered traffic, not an absolute value. That is, a trunk-group grade of service of 0.01 does not mean that exactly one call in a hundred will be blocked during the busy hour. Rather, it means that, given a large volume of traffic, the probability of congestion will tend toward one in a hundred.

Table 1-4 lists typical grade of service specifications for traffic system design. Matching loss as used in this table refers to congestion (blocking) in a switching matrix such that input and output terminations cannot be interconnected via the interstage links. Switching matrix matching loss is not covered in this handbook but the author's *Voice Teletraffic Systems Engineering* contains an entire chapter on the subject.

Table 1-4. Typical Grade of Service Specifications

Parameter	Specification
Trunk group loss probability	0.010
Intraoffice line-to-line loss probability	0.020
Line-to-trunk outgoing matching loss probability	0.010
Trunk-to-line incoming matching loss probability	0.020
Trunk-to-trunk tandem matching loss probability	0.005
Probability dial tone delay exceeds 3 seconds	0.015
Probability operator answer delay exceeds 10 seconds	0.050

The traffic formulas found in this handbook, used to predict grades of service, are all based on probability distributions. Probability distributions are bounded by the values zero and one; therefore, a grade of service (probability of congestion) cannot be negative nor can it exceed unity. Because of this property, the probability of a call not experiencing congestion is one minus the probability of congestion, and vice versa. These relationships are expressed in Equations 1.6 and 1.7.

$$P = 1 - Q \tag{1.6}$$

$$Q = 1 - P \tag{1.7}$$

where P = Probability of congestion
Q = Probability of no congestion

1.5 TRAFFIC FORMULAS AND TABLES

Table 1-5 is a selection guide for the traffic formulas contained in this handbook as a function of their typical applications. The Poisson, Erlang B, and Erlang C formulas, based on the assumption of infinite sources, are referred to as the major traffic formulas. The Binomial and Engset formulas, based on the assumption of finite sources, are used in lieu of the major traffic formulas when the number of sources is small. Figure 1-3 is a decision tree to facilitate traffic formula selection on the basis of the standard traffic assumptions.

Table 1-5. Traffic Formula Selection Guide

Typical Applications	Number of Sources	Blocked-Call Disposition	Holding-Time Distribution	Traffic Formula
Final trunk groups in North American PSTN	Infinite	Held	Constant or exponential	Poisson
Trunk groups and other nondelayed server pools	Infinite	Cleared	Constant or exponential	Erlang B
Delayed server pools	Infinite	Delayed	Exponential	Erlang C
Small PBX or remote switch trunk groups	Finite	Held	Constant or exponential	Binomial
Small line concentrators	Finite	Cleared	Constant or exponential	Engset

Representative full-availability traffic tables, selected on the basis of common telephone industry practice, are provided for the Poisson, Erlang B, Erlang C, Binomial, and Engset distributions. Full availability refers to the assumption that every source has equal access to every server. This assumption is normally true for modern traffic systems. Some older systems, however, many of which are still in use, may be limited-availability systems. Limited-availability tables, such as those found in Siemens' *Telephone Traffic Theory Tables and Charts* and ITT Standard Electrik's *Teletraffic Engineering Manual*, can be used for those systems.

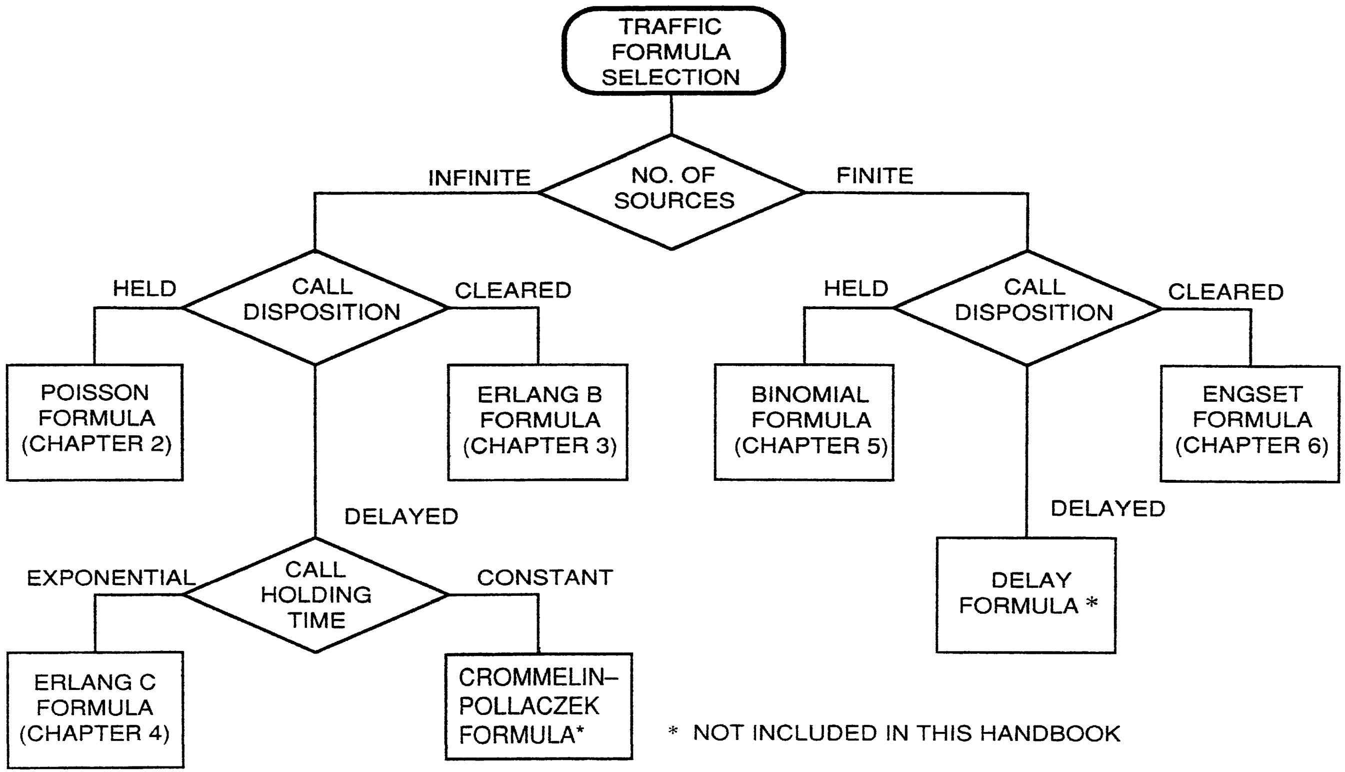

Figure 1-3 Traffic Formula Selection Decision Tree

Tabulated traffic data values in this handbook are rounded off to the least-significant digit as applicable to the specific table. For example, loss probability values have been rounded off to five decimal places. This level of accuracy should be more than adequate for practical applications—very low loss probabilities may indicate overdesign, which is not economically sound.

Where the parameters of a specific application do not coincide with table values, interpolation can be used. However, linear interpolation techniques are not generally satisfactory for these highly nonlinear formulas. Adequate results may be obtained with a graphic technique using semilogarithmic (semilog) graph paper, where loss probability is plotted logarithmically along the ordinate (vertical axis), and offered traffic is plotted linearly along the abscissa (horizontal axis). Figure 1-4 (page 17), a comparison of typical loss probabilities for the Poisson and Erlang B distributions, is an example of the graphic technique. Among other things it shows that, for a given loss probability, less traffic can be offered to a trunk group dimensioned using the Poisson distribution than to one containing the same number of trunks but dimensioned using the Erlang B distribution. That is, the Poisson distribution results in a more conservative design.

1.6 COMPUTER PROGRAMS

Computer programs, useful for interpolating between table values or to determine more precise values for specific applications, are provided in subsequent chapters for the Poisson, Erlang B, Erlang C, Binomial, and Engset formulas. These programs are written in BASIC because it is an easy-to-learn language and is highly standardized. It is the universal programming language for the personal computers found in homes as well as engineering offices. The programs are formatted in an interactive (i.e., dialogue) style to facilitate the user's entry of traffic parameters and include separate lines of code for each step in an attempt to make them more easily understood by those with little or no programming experience.

Readers adept at computer programming may prefer to rewrite these traffic programs, combining a number of steps into a single line of code. Alternatively, the programs can be converted to a language such as FORTRAN, which was specifically designed for computational problem solving. In any case, newly entered programs should be validated by running them against benchmarks, such as the examples in this book, before relying on their output data.

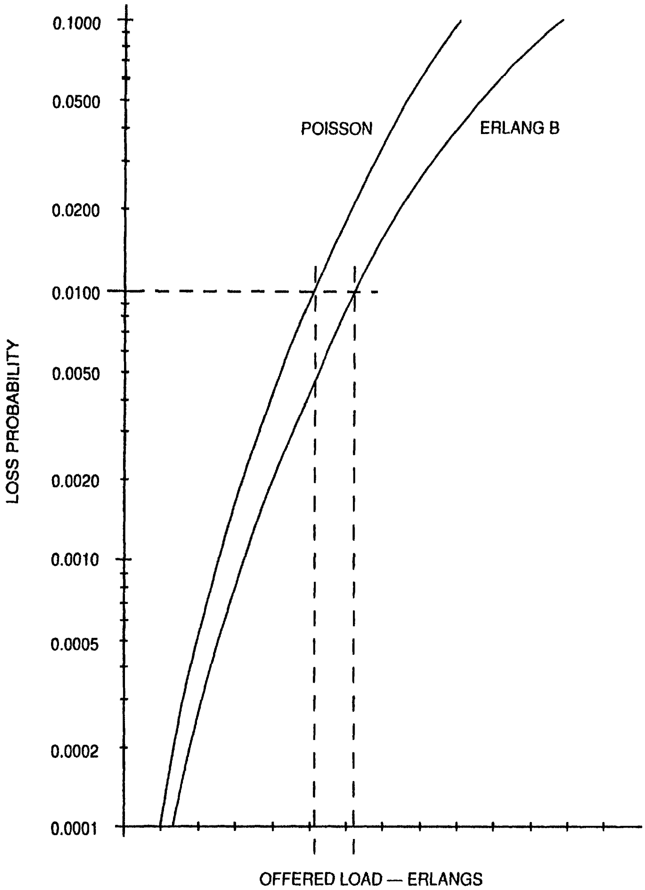

Figure 1-4. Graphic Comparison of Poisson and Erlang B Distributions

A word of caution—computers are subject to overflow when dealing with very large numbers. This limitation is a function of the computer hardware and software, which can only process numbers within a finite range. Overflow often occurs when calculating traffic formulas, which typically involve calculation of factorials, numbers raised to the *n*th power, or infinite sums. The traffic programs provided herein have been written to avoid overflow conditions where possible. Overflow may still occur, however, when calculating the loss probability for a high traffic volume offered to a large number of servers, or some combination of these or other traffic parameters is encountered.