

# USER REACTION TO TRANSMISSION QUALITY

## A COST MODEL

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**ABSTRACT** Customer Opinion Models have been used extensively to aid in the Planning, Design and Operations of Public and Private switched telecommunications networks. User Reaction models now extend the conventional opinion models to provide direct relationships between the objective parameters which define network performance and the Users' Subjective Opinions, their Overt Actions and associated Operating Cost penalties. This paper presents a cost model based on predicted actions which network users may take when they perceive degraded transmission quality. The user actions; Terminating Calls Early, Redialing Calls, Calling Operators for Assistance and Rebates, and Reporting Troubles, all increase rapidly and exponentially as network parameters degrade from optimum performance. Costs associated with this user activity increase even more rapidly, exceeding implementation and equipment costs in severely degraded situations. These hidden costs, caused by customer dissatisfaction and scattered throughout industry operations, usually exceed the costs to remove the deficiencies, improve circuit quality and minimize the potential for customer migration to competitive services. Near-optimum transmission performance is likely to be the more economical operating point for service providers on both sides of the Exchange and Inter-Exchange boundaries.

**1. INTRODUCTION** This paper addresses, by example, parametric studies on Loss, Noise and Echo performance on Public Switched Network (PSN) Connections. As transmission performance decreases, the associated customer overt actions increase exponentially; often exceeding several hundred percent increase compared with the nominal activity associated with near-optimum performance. A cost function is presented which shows accompanying increased expenses which are borne by industry and users; costs which are imbedded throughout much of the day-to-day operation. This increased operating expense eventually results in decreased profit margins, increased tariff rates, or both, for the service providers and customers alike. Costs associated with increased customer activity such as; calls terminated early, calls redialed and calls back to operators may exceed several hundred or even several thousand dollars per inter-office circuit per year. Design, Installation and Maintenance activity required to provide better quality service can often be justified on cost considerations alone. The improved performance provides significant contribution to business profitability as a recurring savings, while customer satisfaction is improved. Near-optimum transmission performance, rather than wide-ranging impairment limits, should be supported by the industry whenever reasonably feasible.

**2. NETWORK TRANSMISSION PERFORMANCE** It is important for the telecommunications industry to work cooperatively to maintain acceptable performance for the many services offered on the Public and Private Switched networks [1], [2]. Modern switching technology and our national policy allow the interconnection of many combinations of transmission facilities, multiplex equipment, public switching exchanges, PBXs and Remote Switching Units for both voice and data services. Once the switching wizardry has accomplished its tasks, users then have but one goal for the established connections; to faithfully convey their desired messages to their final destinations. Unfortunately, transmission performance impairments can and often do vary over sufficiently wide ranges to produce situations where all of the parts of an established connection meet their individual limits, but the resulting performance is unacceptable or even unworkable. For a normal call passing once through the Public Switched Network, the probability of encountering such poor performance is relatively small. However, connections involving multiple passes through the public and private networks and their combinations encounter increasing occurrence of the unacceptable or unworkable connection. It is recognized that digital

transmission technology can reduce this potential for accumulating impairments. However, digital connectivity in the national network is not yet available except in special situations, and will not be economically available to all customers for perhaps decades. In the meantime, the industry must cope with the evolving digital technology and its complex mix with widespread analog plant. During the transition years, quality may actually degrade in whole network pockets or serving areas, depending on the mix of facility types and methods of implementation. Inter-office circuits in the PSN, especially those in the Exchange Access networks, are critical links that play a key role in the ability to provide quality performance on end-to-end connections.

**3. NETWORK PERFORMANCE MODELS** How can one estimate the performance of such a large and complex system as a national communications network? The final verdict on how well a system performs is based on customers' or users' perceptions of the quality of the service received. For decades, customer opinion models have been used to predict how customers rate various combinations of impairments such as received volume, loudness loss, received noise and talker echo. These models, called Grade-of-Service or Customer Opinion models, are well documented in the literature [3], [4], [6]. They have evolved into a mature discipline for estimating subjective opinion especially to help in the decision processes in Network and Transmission Planning.

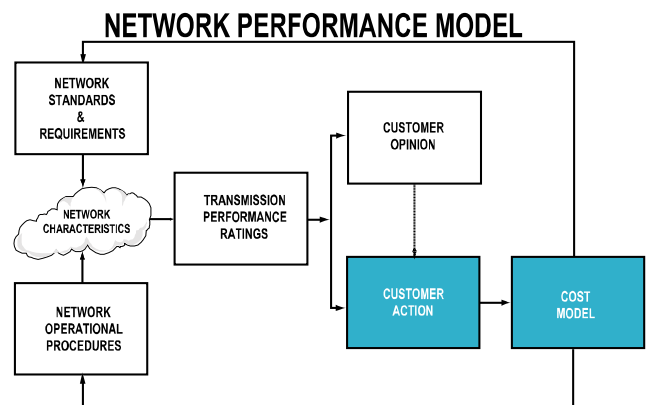


FIGURE 1

Figure 1 shows a block diagram for an extended modeling process. The network characteristics or objective measures (Loss, Noise, Echo Path Loss, etc.) result from the collective processes of Network Planning, Industry Standards, Design Methods, and Operational Procedures including Installation and Maintenance methods and requirements.

These objective network statistics are used in the performance models to calculate Transmission Ratings from which the customer opinions are estimated. Extensions of the Opinion Models have been developed to predict the actions which customers will take as the performance of network connections vary over a wide range of impairments [1], [5]. The customer action is shown to be highly correlated with the customer opinion and is predicted, mathematically, from the Transmission Ratings. Finally, the author has added a cost model that predicts the impact on operational costs of a telecommunications network as a function of the customers overt actions.

**4. VOICE QUALITY** Three key impairments determine the users' perception of the quality of voice transmission on a telecommunications network: Loudness Loss, Received Noise, and Talker Echo. There are other impairments which can affect voice quality such as bandwidth and

distortion, but Loss, Noise, and Echo are the dominant three. The Transmission Ratings and Customer Opinion models used in the analyses throughout this paper account for the interactive effects of all three impairments; including the user's sensitivity to echoes in the presence of transmission delay.

4.1 **LOUDNESS LOSS** affects the user's ability to hear. It is a measure of the acoustic loss of an end-to-end connection and includes; the acoustic-to-electrical conversion characteristics of the transmitting station, the end-to-end electrical loss of the established connection and the electrical-to-acoustic conversion characteristics of the receiving station.

It is important to control both sides of the statistical distribution of connection loss. Too much loss makes hearing more difficult for the user; eventually reaching the point where speech intelligibility is lost. Too little connection loss may cause uncomfortable loudness and reduces stability margins, increasing the chances for hollow, "rain barrel-like", "tinny" or unnatural sounding circuit connections.

It is desirable to add loss in a connection to reduce the level of echoes that are received back at the talker or listener station. However, adding too much loss impairs the users' ability to hear. This gives rise to the classic engineering tradeoff that must be accompanied in the network and circuit design process. There exists an optimum loss design for a given set of network characteristics. [9], [10].

4.2 **RECEIVED NOISE** in the opinion models is the composite of all noise sources translated to the received end of a connection; including the individual circuit noise, quantization noise and background noise at the users' location. Too little noise may present a problem because a user may perceive the connection as being too quiet or even as "dead circuit".

4.3 **TALKER ECHO** is accounted for in the Opinion Models by characterizing the statistical distributions of the Talker Echo Path Loss and Delay in the round trip path from the talker station to the major sources of signal reflections and returning to the receiver of the Talker's station. Talker echo becomes increasingly annoying, even to the point of distraction, as the echo path transmission delay increases.

**5. CUSTOMER OPINION** Models of customer opinion are derived mathematically from subjective tests. Participants vote on a scale of Excellent, Good, Fair, and Poor, giving their perceptions of various combinations of LOSS, NOISE, and ECHO impairments. This four-point scale is often given a 4,3,2,1 weighting to derive a figure of merit called the Mean Opinion Score MOS). Some models described in the Literature discuss a five-point scale including the Unsatisfactory Rating below the Poor category. The four-point scale is widely used in User Reaction Tests which have been conducted both Nationally and Internationally.

It is important to note the ability of a population of users to perceive relatively small differences in impairments on various connections. There is a common misjudgment that voice telephony users do not perceive relatively large changes (several dB) in connection loss or received noise. This is partly true where a connection is operating near the optimum range of loss or noise. But, performance deteriorates at an increasing rate as loss or noise is increased dB for dB. If two customers are conversing over an established connection and the connection loss is suddenly increased by 3dB, this customer pair may not detect the insertion of the extra loss. However, a population of users; for example, 1000 participants, will accurately assess which connection has the poorer performance. Their decision threshold, as a population, is considerably more accurate, detecting much smaller differences than would individual voters. The fallacy of applying just noticeable differences to telecommunications users is that subsequent insertions of even 1dB of loss, if continued, will eventually lead to a non-working

connection. Transmission impairments and the associated customer opinion scales form a continuum from very good to very bad performance. There are no magic impairment limits within which connections are equally good and beyond which the connections are suddenly bad. As shown in the following sections, users' actions increase at an exponential rate along the continuous impairment and opinion scales. The cost penalties associated with these overt user actions also increase continuously and exponentially as performance degrades.

**6. CUSTOMER ACTION** Telecommunications users accurately perceive the presence of transmission impairments on calls that they initiate or receive in the public and private switched networks. As transmission parameters degrade from optimum levels, the percentage of connections which are rated "Poor" quality rapidly increases from a few percentage points to situations where the majority vote is "Poor". Although the user population is usually quite forgiving, and will tolerate considerable degradation before complaining, a smaller subset will take action. This user reaction increases exponentially as performance degrades.

6.1 **TERMINATE CALLS EARLY** – Users react to poor transmission performance by concentrating on conducting essential transactions during the conversation, if possible. However, they may give up trying to use the connection and terminate the call early, feeling that they were unable to complete their conversation to their satisfaction. There is an implied cost penalty due to lost revenue. Certainly there is an annoyance penalty to the user. Transmission impairments may force the user to take longer to convey a given message, implying hidden costs to the users for their own time involvement and higher costs to transact the required conversation. In the face of the chronic difficulty, users who have an alternative may migrate to a competitive service.

6.2 **REDIAL CALLS** – Users may give up on the quality of a given connection by disconnecting the call and redialing to establish a new connection. There are cost penalties implied for both the user and the service providers. Redialing calls requires the use of common equipment that is shared to establish calls. As service quality is degraded, an increasing percentage of redialed calls may require that extra modules be provided in the common equipment to accommodate the traffic – a provisioning cost. Users will be charged for two or more calls if they do not call back for rebates. Again, the users are required to spend more time to conduct their transaction; a cost penalty on their time and a higher charge for the multiple calls. The annoyance factor rises and the users may migrate to competitive services, given an alternative.

6.3 **CALL OPERATOR FOR ASSISTANCE** – As transmission performance degrades, an increasing number of users will call back to an Operator to complain about the quality of their call and to ask for better connections and for rebates. Operational costs increase significantly, due to required operator time, cost of processing rebates, the rebate amounts, and carrying charges due to computer databases and operational systems that are used to log, track, analyze, and resolve the complaints. The annoyance factor increases for the user. Once again, given an alternative, some subset of users will migrate to a competitive service.

6.4 **REPORT TROUBLES TO SERVICE BUREAU** – There are additional actions that customers take to report troubles. For average calls on the public switched network, it is estimated that from 1 call in 1000 to 1 in 10,000 calls [5,p.20-6.6] generate a complaint to the Customer Service or Trouble Bureau. This rate of Trouble Complaints is also expected to increase exponentially as the transmission quality degrades from the near-optimum level.

6.5 **MIGRATE TO COMPETITIVE SERVICE** – The final complaint that a customer may register, in the face of chronic difficulty, is to quit and

switch to a competitive service, where alternatives are available. As the degree of service degradation increases, the rate at which migration occurs is expected to rise at least as rapidly as the trouble complaint activity. The lost revenue can be estimated from average revenue per customer statistics. However, there can be no comfort in placing a price tag on lost customers due to poor quality service. The ultimate cost penalty can be the inability of a service provider to retain its customer base and stay in business.

**7. USER REACTION TESTS – BASIS FOR THE COST MODELS**

Earlier forms of the Grade-of-Service models were derived from opinions obtained in experiments conducted with participants operating in controlled environments [3], [6]. The resulting customer opinion models have served the national and international network planners well.

During the years 1975-1980, a substantial number of User Reaction Tests were conducted on various types of long-haul connections between major cities in the public switched network [1], [7], [8]. The rich database includes more than 25,000 customer interviews on over 100 circuit conditions. Analysis of the results reveal a high correlation between the customers' opinions and their actions.

Customers received call-back interviews to obtain their opinions of the quality they experienced on connections they had just completed in their normal calling patterns. These customers were asked if the quality of transmission was acceptable during the conversation. If they answered NO, they were then asked if the difficulty caused them to terminate the call early, replace the call or dial an operator for assistance. Every customer was asked to rate the connection quality on a scale of Excellent, Good, Fair, and Poor. For each test circuit condition imbedded in the Lon-Haul Network, from 100 to 500 interviews were obtained. A weighting of 4,3,2, or 1 was assigned to the Excellent, Good Fair, or Poor ratings and the Mean Opinion Score (MOS) was calculated for each circuit condition.

When all circuit results are pooled and quantized into MOS cells, the Customer Action vs MOS relationship results as given in Table 1. The Customer Action increases rapidly as the Mean Opinion Score decreases by 0.2 steps. The User Opinion rating of Unacceptable (%U) is approximately equal to the sum of the Fair (%F) plus Poor (%P) ratings.

The important relationship between customer action and opinion cannot be observed with a small number of opinion samples for given circuit conditions. The results only became observable as this large database of over 25,000 interviews was gathered. The percent of calls dialed back to an operator for assistance appears very low (.19% in the best performance category). However, consider the traffic that a single inter-office circuit normally carries; in the order of 16,000 to 20,000 calls per year. For example, if the quality of an inter-office circuit causes the connection ratings to degrade from a good rating of 3.3 to a poorer rating of 2.9, the number of calls back to operators for assistance increases from about 50 to nearly 200 occurrences; a 400% increase. Assuming a cost of \$5.00 for each transaction including; operator handling time, rebates, trouble report handling and computer database overhead, the annual operating costs for this category of customer action jumps from \$250 to nearly \$1000. The service provider could invest some portion or all of the \$750 savings in one year to obtain the better circuit performance. The cost reduction is an annually recurring savings.

Barry Kort [5] has provided a mathematical model of the User Action categories as a continuous function of the Transmission Rating, extending the author's analysis of the quantized Mean Opinion Score. The end result is a consistent set of continuous functions by which the customers' opinions and actions are estimated. From the Customer Action estimates, the impact on operational costs can be predicted.

**USER REACTION TEST RESULTS  
CUSTOMER ACTION VS. OPINION**

Subjective Opinion	Overt Action				Number of Interviews
	Mean Opinion Score	%Calls Rated U (%U)	%Calls Term. Early	%Calls Actually Replaced	
<2.79	28.49	9.59	3.67	2.54	709
2.80-2.99	18.67	4.63	1.82	1.10	2,638
3.00-3.19	12.67	3.32	1.34	.47	5,092
3.20-3.39	8.02	1.94	.84	.32	12,693
3.40-3.59	4.88	1.53	.58	.19	4,123

N = 25,255

TABLE 1

**8. CUSTOMER ACTION COSTS** From the User Reaction Tests, it is seen that Customer Action is highly correlated with the Customer Opinion of Transmission Quality. Figure 2 is a bar graph of the percent of calls that were dialed back to an operator for assistance. This category of Customer Overt Action increases exponentially as the MOS and Transmission Ratings decrease.

**OPERATOR ASSISTANCE AND  
MEAN OPINION SCORE**

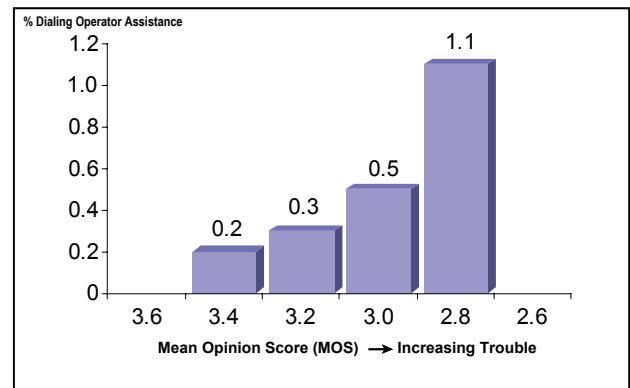


FIGURE 2

Assuming a cost of \$5 per complaint back to an Operator and an annual traffic on inter-office circuits of 16,000 calls per circuit, then for the best MOS performance cell in Figure 2 (0.2%):

$$\text{COST} = (0.2\%) \times 16,000 \times \$5.00 = \$160/\text{CKT}/\text{YR}$$

When this calculation is applied to each MOS cell in Figure 2, operational costs for Complaints to Operators increase from \$160 to \$880 per circuit per year as shown in TABLE 2.

**CUSTOMER ACTION – COMPLAINTS TO OPERATION**

MOS	Annual Cost/Circuit	%CO	\$Cost
3.5	0.2		160
3.3	0.3		240
3.1	0.5		400
2.9	1.1		880

TABLE 2

The model is extended to include cost elements for Calls Terminated Early and Redialed Calls. Actual costs for the activity in these latter overt action categories are not easily quantified and depend very much on whose costs are being analyzed; calling customers, service providers (operating entities) or called customers. However, the annoyance factors mentioned earlier are real. When customers encounter poorer quality on calls placed on services to which they subscribe, the operating entities are vulnerable to increased complaints and possible loss of an increasing number of subscribers in the case of competing services. Costs are assigned to each action category in the sense of an Operations Research cost function, the account for the user and provider penalties and frustration factors. For example, if weightings of 1, 2, and 5 are used for the Calls Terminated Early (%TE), Redialed calls (%RE), and Complaints to Operator (%CO), respectively, the annual cost function is:

$$\text{COST} = [(1 \times \%TE) + (2 \times \%RE) + (5 \times \%CO)] \times \text{NC}$$

Where NC = Number of Calls carried per circuit per year.

This costs function is applied to the Loss, Noise and ERL sensitivity studies discussed in the following sections. One additional cost factor, Trouble Reports to Service Bureaus, is also allowed but is set to zero in the following performance analysis, to stay on the conservative side of the cost penalty estimates.

**9. PERFORMANCE ANALYSIS** Actual analyses of given situations require the use of statistical characterizations of the loss, noise, echo path loss, and echo path delay distributions for each link in the end-to-end connections under study. GOSCAL, an acronym for Grade-Of-Service CALCulations has been implemented in several evolving versions of computer programs to provide the complex analysis. PCGOSCAL is a recent, expanded version for PC applications that implements the functions implied in Figure 1:

- a) Simulates Network Connections
- b) Accepts statistical descriptions of the Objective Transmission Parameters for each Network Link
- c) Calculates Transmission Ratings
- d) Provides Estimates of Customer Opinions
- e) Provides Estimates of Customer Actions
- f) Calculates the Operational Cost Function

The following parametric studies were accomplished using PCGOSCAL to perform the connection simulations.

**10. APPLICATION/LOSS, NOISE AND ECHO PATH SENSITIVITIES**

The following study makes use of the Customer Opinion, Customer Action and associated Cost Models, using the Long Toll Model Transmission ratings, to analyze the users perceptions of Loss, Noise and Echoes on the Public Switched Network.

10.1 LOSS SENSITIVITY – Figure 3 shows a typical end-to-end connection. Calls are completed from Station A through a local loop and Public Switched Network Connection to a local loop and station at B. Loss distributions are shown for each link and for the resulting end-to-end connection. Similar statistics are included in the simulation for the noise and echo path characteristics for each link.

**NORMAL PASS THROUGH PSN  
END-TO-END LOSS DISTRIBUTION**

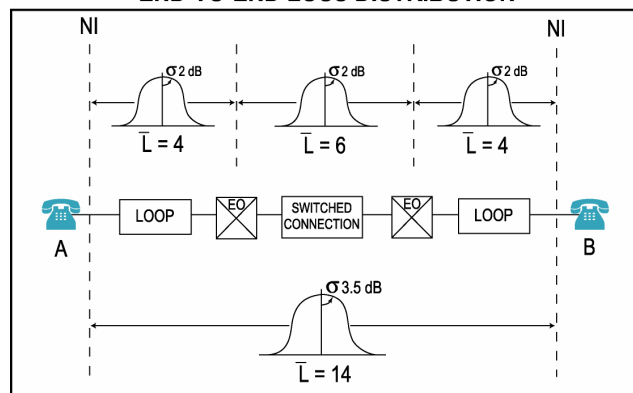


FIGURE 3

**CUSTOMER ACTION COSTS**

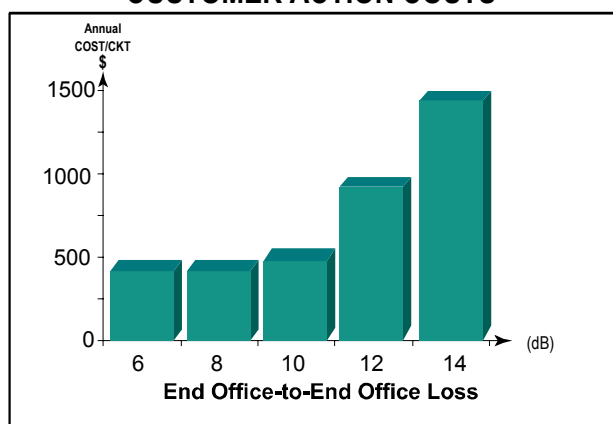


FIGURE 4

When the End Office-to-End Office loss is varied parametrically, the User Reaction Cost function varies as shown in the bar chart of Figure 4. Assuming a traffic load of 16,000 calls per inter-office circuit per year, the cost function is relatively flat at about \$410/CKT/YR for End Office-to-End Office Losses of 6 to 8dB.

At 10dB, the cost function jumps to \$540/CKT/YR; an increase in operational costs of \$130/CKT/YR. Costs increase dramatically to about \$810/CKT/YR and \$1250/CKT/YR for 12dB and 14dB, respectively. Maintenance activity should identify those circuits that are not set for the nominal loss design. These circuits usually can be realigned to the more optimum loss range. It is recommended that the industry adopt an End Office-to-End Office loss requirement of less than 10dB; preferably 8dB where possible.

10.2 NOISE SENSITIVITY – Figure 5 shows the connection used to vary the noise introduced by transmission facilities in the Inter-Exchange Network. Assuming a zero-loss design for the IC circuits, the analysis also applies to noise contributed by the Exchange Access circuits, until the IC circuit noise dominates.

## NORMAL PASS THROUGH PSN END-TO-END LOSS DISTRIBUTION

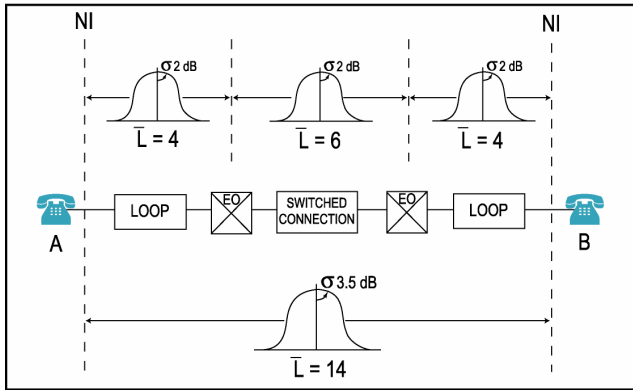


FIGURE 5

When the Inter-office noise is varied, the User Reaction Cost function varies as shown in the Figure 6. At 25 dBmCO, the cost function is \$410/CKT/YR and increases dramatically to over \$2700/CKT/YR at 45 dBmCO. At 35 dBmCO, the cost function has increased to over \$600/CKT/YR.

### CUSTOMER ACTION COSTS

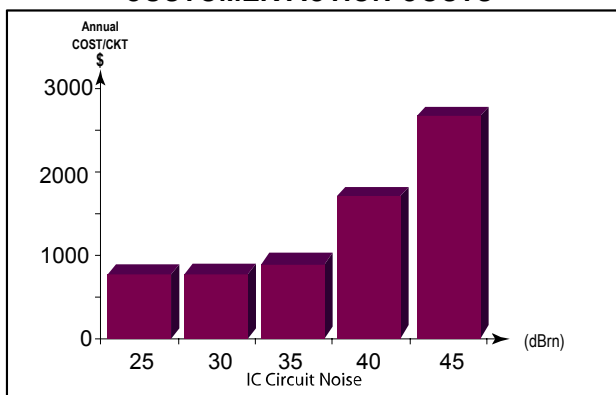


FIGURE 6

The additional cost of about \$200/CKT/YR could provide operating companies with a significant annual savings if regular maintenance activity is performed to reduce the circuit noise. It is recommended that the industry adopt a voluntary circuit noise requirement of less than 30 dBmCO. Long-Haul, high capacity, AM and FM analog systems generally are not able to achieve this requirement; especially on fully loaded systems. However, the savings incentive to operating entities is overwhelming to reduce the noise on the broadband systems by keeping the circuits properly maintained and aligned to near their design performance capability. Digital facilities easily achieve less than 25 dBmCO noise performance.

As an example, reducing the circuit noise from 45 to 40 dBmCO could save over \$1600 per circuit per year. On a broadband system carrying 3,000 active circuits, the annual savings may approach \$5 million, assuming all circuits may be improved. In some cases, this might be accomplished by adjusting system signal loading and aligning a common equipment element such as a microwave generator.

10.3 ECHO SENSITIVITY – Figure 7 gives the User Reaction Cost function as the Echo Return Loss (ERL) is varied at the End-Office.

ERL is a measure of the impedance match between the subscriber loop

impedance and the impedance of the balance networks used on the 4-wire to 2-wire conversion points at the End-Office or comparable location (e.g., a Remote Switch Point in a Digital Exchange environment). When the Echo Return Loss is varied from 6dB to 20dB, User Reaction Costs decrease from \$850/CKT/YR to \$200/CKT/YR normalized to 10,000 calls. The conventional compromise network balance for traditional 2-wire exchanges yields a cost penalty of about \$450/CKT/YR as shown for the 11dB (Sigma=3dB) point. It is interesting to note that earlier work by Spang[9] recommended that the terminal balance at toll offices be increased from 18dB to 22dB for the fixed loss network design plan. This is equivalent to the 16dB point on Figure 7, when the Exchange Access circuit adds 6dB loss to the echo path.

From Figure 7, it is recommended that the industry adopt a voluntary requirement of greater than 16dB Echo Return Loss or equivalent Echo Path Loss for new terminal equipment whenever possible.

### PSN CONNECTION CUSTOMER ACTION COSTS

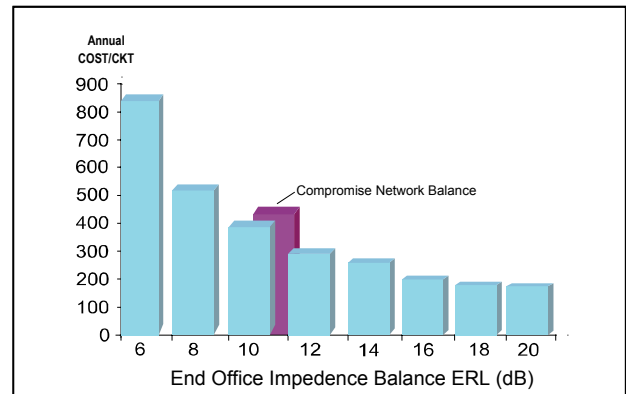


FIGURE 7

**11. CONCLUSION** From the results of the User Reaction Models applied in the Loss, Noise, and Echo sensitivity studies, customers perceive significant degradations in transmission performance over the range of impairments studied. Users may take action up to ten times more often in response to the degradations when compared with near-optimum public switched network calls. The sensitivity studies provide economic justification for the industry to maintain tight control of the transmission parameter variations that are allowed on inter-office circuits. End Office-to-End Office Loss should be maintained less than 10dB; preferably under 8dB where possible. Inter-office circuit Noise should be maintained to better than 30 dBmCO where feasible. Echo Path Loss, from the Point of Termination at the Inter-exchange/Exchange carrier boundary to the Exchange End Office and return, should be greater than 22dB wherever possible. Savings to operating entities can be substantial. The User Reaction Cost Model suggests that near-optimum network transmission performance may be the more economical operating point for the industry to embrace as it moves forward with a new set of performance standards. Higher quality may in fact be achieved at lower overall costs.

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From 1975-1983, Larry was a delegate to the international meetings of CCITT, on Transmission Standards. He has published numerous papers on transmission and network performance, is a member of IEEE and, from 1980-1986, chaired the IEEE Subcommittee on Telecommunications Systems Performance. He is an active participant in the Exchange Carriers Standards Association and currently chairs the T1Q1.1 Subworking Group on Transmission Loss and Level Plans. He holds a BSEE and MSEE from Northeastern University, completed the Graduate Study Program at Bell Laboratories and post graduate studies in Computer Science at Stevens Institute of Technology. Larry resides with his family in Gilford, New Hampshire, where he is chairman of the Board of Governors for Faith Christian Academy.