The Schultz curve 25 years later: A research perspective[a]

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The contemporary technical rationale for assessing effects (''impacts'') of transportation noise on communities rests in large part on a purely descriptive dosage-effect relationship of the sort first synthesized by Schultz [J. Acoust. Soc. Am. **64**, 377–405 (1978)]. Although U.S. federal adoption of an annoyance-based rationale for regulatory policy has made this approach a familiar one, it is only one of several historical perspectives, and not necessarily the most useful for all purposes. Last reviewed by the U.S. Federal Interagency Committee on Noise (FICON) 10 years ago, the accuracy and precision of estimates of the prevalence of a consequential degree of noise-induced annoyance yielded by functions of noise exposure leave much to be desired. This tutorial article traces the development of the dosage-effect relationship on which FICON currently relies, in a wider historical context of efforts to understand and predict community response to transportation noise. It also identifies areas in which advances in genuine understanding might lead to improved means for predicting community response to transportation noise.
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I. INTRODUCTION

A quarter of a century ago, the *Journal of the Acoustical Society of America* published what proved to be an influential article on community reaction to transportation noise exposure (Schultz, 1978). Schultz demonstrated that the results of social surveys conducted in disparate cities and languages on the effects of aircraft and surface transportation noise could be interpreted in common terms, and usefully summarized in the form of a dosage-effect relationship. Successors to this relationship are relied upon today to characterize noise impacts for purposes such as planning transportation infrastructure projects, and for determining eligibility for federal funding of large-scale noise mitigation projects.

Schultz's 1978 study was a major work of scholarship and technical insight that began the integration of a scattered world literature on community-level noise effects. It helped to promote a measure of time-weighted average noise exposure as a primary predictor of community reaction to noise, established the current paradigm for analysis of such effects, served as the impetus for considerable subsequent research, and offered the prospect of a much-prized technical rationale for environmental noise regulation.

Although Schultz's approach eventually came to be regarded as the conventional wisdom, his paper remained controversial for years (*cf*. Kryter, 1982). Initially, many took issue with details of his conversions of diverse noise metrics into Day-Night Average Sound Level (abbreviated DNL and expressed symbolically in mathematical expressions as L_{dn}) or found fault with his adoption of self-reported annoyance (rather than speech or sleep interference, or complaints) as the dependent variable of his dosage-effect relationship. Others objected to Schultz's rejection of a measure of central tendency of annoyance as a dependent variable, and to his preference for a single relationship to summarize reaction to both aircraft and surface transportation sources. Schultz and others eventually suggested alternate fitting functions, reanalyzed and updated the corpus of findings available for analysis, identified source-specific dosage-effect relationships, and attempted to develop theory-based underpinnings for Schultz's empirical relationship.

Enough has been learned in the years following publication of Schultz's pioneering work on community reaction to transportation noise to warrant reexamination of the research and regulatory paradigms that followed from it. Before doing so, however, it is helpful to review (1) the context in which Schultz conducted his original analyses, and (2) subsequent research findings, understandings, and practical applications of Schultz's work.

II. CONTEXT OF SCHULTZ'S ANALYSIS

The origins of modern legislative and regulatory concern with transportation noise exposure in the United States can be traced to the introduction of jet aircraft at military bases in the early 1950s, to the start of passenger jet service in 1958, and to development of the national highway network in the 1960s.[1] The higher levels and the distinctive features of the noise emissions of jet aircraft *vis-a-vis* those of propeller-driven aircraft, as well as expansion in numbers of flight operations, elicited strongly adverse reactions in communities near military airbases and civil airports. By the 1970s, increased highway traffic noise led to large-scale studies of relationships among traffic flow parameters, noise emissions, and community reaction.

The U.S. Noise Control Act of 1972 was a legislative acknowledgment of national concern with the effects of residential noise exposure. The Environmental Protection Agency's ''Levels Document'' (EPA, 1974), a product of the Noise Control Act, identified a time-weighted average measure of sound level (eventually standardized as DNL) as a convenient expression of the total environmental noise of

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[a] Review and tutorial paper.

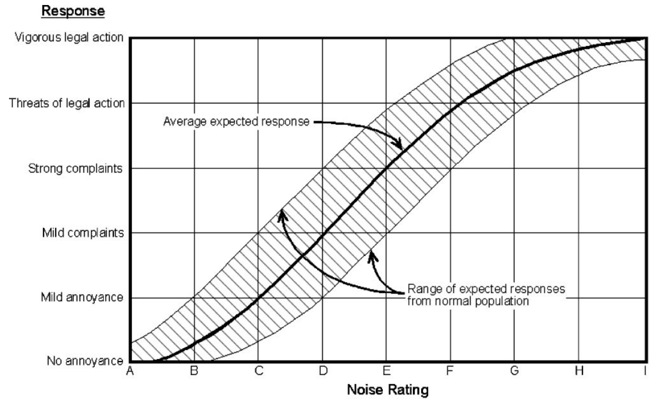

FIG. 1. Relationship between community noise rating and predicted behavioral consequences of environmental noise exposure, adapted from Fig. D-16 of Appendix D of ‘‘Levels Document’’ (EPA, 1974).

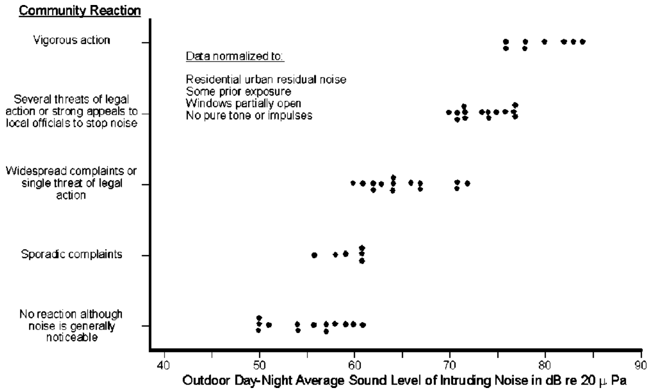

FIG. 2. Community reaction to intrusive noises of many types as a function of the outdoor Day-Night Average Sound Level of the intruding noise. (Adapted from Fig. D-7 of EPA Report 550/9-74-004, ‘‘Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety,’’ March, 1974.)

communities.[2] Schultz’s work started in 1976, under contract to the U.S. Department of Housing and Urban Development. HUD sought to develop consistent criteria for approving federal financial participation in housing projects in neighborhoods with varying degrees of environmental noise exposure.

At the time, the state of the art of assessing the habitability of housing in noisy areas had advanced little from the pioneering work on ‘‘community noise ratings’’ conducted throughout the 1950s for the U.S. Air Force and for the Port of New York Authority (*e.g.*, Stevens and Pietrasanta, 1957; Beranek *et al.*, 1959; Galloway and Pietrasanta, 1963). The early approach to characterizing adverse community reaction to aircraft noise focused on prediction of its overt (complaint and similar) behavioral consequences. Rosenblith *et al.* (1953) and Stevens *et al.* (1955) devised a framework for interpreting the findings of 20-odd case studies of community reaction to aircraft noise that characterized community reaction in terms of ‘‘sporadic’’ through ‘‘widespread’’ complaints, ‘‘threats of community action,’’ and ‘‘vigorous community action.’’ Figure 1 summarizes the relationship that Rosenblith *et al.* inferred from their case studies.

A ‘‘Community Noise Rating’’ (CNR) value was determined by first estimating a ‘‘noise level rank’’ from a set of idealized spectral shapes for community noise. These shapes were derived from laboratory findings about the loudness of sounds in different frequency bands. The noise level rank was modified (normalized to standard conditions) by site-specific factors such as ambient noise levels, time of day and year, tonal content, dynamic range of noise intrusions, and novelty of exposure.

CNR-based assessment of community reaction to environmental noise required a detailed case study, involved more-or-less arbitrary judgments about the detailed nature of noise exposure, and made no effort to account for the range of reactions associated with the same rating level (for example, from ‘‘sporadic complaints’’ to ‘‘threats of community action’’ at rating ‘‘E’’) in different communities.[3] The CNR scheme was purely descriptive, and identified no mechanisms by which noise exposure was transformed into complaints.

Despite its limitations, CNR remained influential for two decades after its initial formulation, as is recognizable in Fig. D-7 of EPA’s 1974 Levels Document (reproduced above as Fig. 2). CNR evolved in the 1960s into an increasingly simplified Composite Noise Rating (CNR-2), and eventually into a Day-Night Average Sound Level (modeled on California’s ‘‘Community Noise Equivalent Level,’’ which included 5- and 10-dB evening and nighttime weightings).

As late as EPA’s ‘‘Levels Document’’ (pp. 20 *et seq.*), non-health-related effects of noise on people were addressed under the rubric of ‘‘Activity Interference/Annoyance.’’ The ‘‘activity interference’’ portion of this concern referred to masking of communication by environmental noises, as indicated by references to ‘‘listening to a desired sound, such as speech or music’’ and ‘‘interference with speech intelligibility.’’ The explanatory appendices to EPA’s Levels Document are replete with further evidence that annoyance was not the effect of principal concern in identification of protective noise levels. Figures D-7, D-8, and D-16 (of which Figs. D-7 and D-16 are reproduced here as Figs. 2 and 3) of Ap-

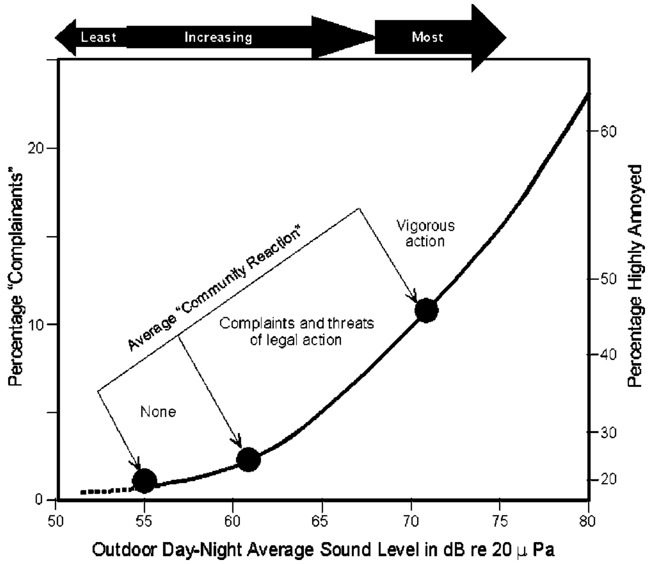

FIG. 3. Illustration of vestigial influence of CNR methodology on assessment of community reaction to aircraft noise exposure in EPA’s 1974 ‘‘Levels Document’’ (Fig. 16, Appendix D).

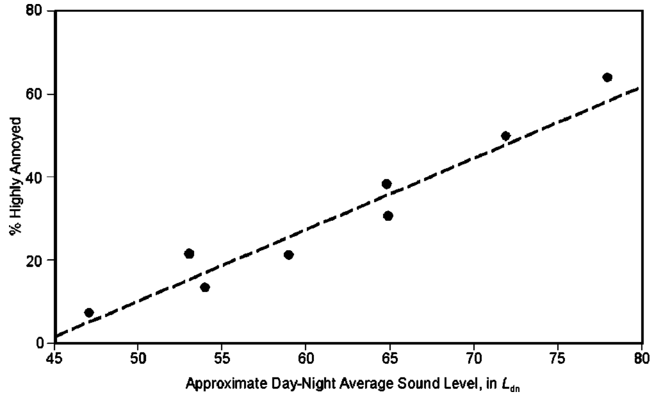

FIG. 4. Early estimate of relationship between cumulative noise exposure and prevalence of aircraft noise-induced annoyance contained in supporting documentation for EPA Levels Document.

pendix D of the Levels Document (''Noise Interference with Human Activities and Resulting Overall Annoyance/Health Effects'') make it clear that EPA's use of the term ''community reaction'' refers to complaints. Figure 2 is merely a reworking of the Rosenblith and Stevens case study complaint information, intended to reduce the variance in each reaction category. Figure 3 is an attempt to relate complaint and annoyance data to noise exposure information through the early dosage-effect relationship shown in Fig. 4. In other words, EPA's 1974 rationale for identifying sound levels requisite to protect public health and welfare was based on speech interference and complaints rather than annoyance:

''Thus, the levels identified [in the Levels Document] primarily reflect results of research on community reaction [*i.e.*, complaints] and speech masking'' (EPA, 1974, p. 21).

The first large-scale social survey that attempted to associate attitudinal factors with noise exposure estimates was conducted in the vicinity of London Heathrow Airport in 1961. The supplementary reports to EPA's Levels Document were cognizant of the results of this and other early social surveys, but not sufficiently swayed by the quantity or interpretability of social survey data to base identification of protective sound levels on this information. Figure 4 illustrates the interpretation afforded to annoyance data at the time of publication of the Levels Document. Several aspects of Fig. 4 remain of interest today: (1) rejection of average annoyance in favor of ''high'' annoyance as the measure of noise effect; (2) reliance upon a fitting function with an assumed form (linear, in this case) to describe the field data; (3) use of the then-newly defined DNL as the predictor of the prevalence of annoyance; and (4) characterization of about a third of the population as highly annoyed by aircraft noise at $L_{\mathrm{dn}} = 65\,\mathrm{dB}$. It was not until a decade later that Schultz's more extensive work lent enough credibility to such analyses to shift the technical rationale underlying noise regulatory policy from complaints and speech interference to annoyance.[4]

III. SUBSEQUENT EXTENSIONS OF SCHULTZ'S ANALYSIS

The segment of a third-order polynomial function that Schultz used to describe his 11 original clustering surveys ($\%\ \text{Highly Annoyed} = 0.8533L_{\mathrm{dn}} - 0.0401L_{\mathrm{dn}}^2 + 0.00047L_{\mathrm{dn}}^3$) was an informal approximation, rather than a relation derived from regression analysis. The limitations of both the data set from which the arbitrary fit was derived and of the fitting function itself were readily apparent. Perhaps the most striking aspect of the data set that Schultz and his successors (*e.g.*, Fields, 1991) assembled is its great variability (*cf.* Schomer, 2002, Fig. 6). Noting the relatively small amounts of variance accounted for by relationships between noise exposure and the prevalence of annoyance in individual studies, Job (1988) inferred that nonacoustic factors that were not reflected in DNL values played a role comparable to exposure itself in determining community reaction to noise.

Schultz recognized the preliminary nature of his original synthesis curve, and did not expect it to remain the final word for long. For example, Fidell *et al.* (1988) modeled the shape of a fitting function on the basis of first principles[5] rather than purely descriptive regression analysis. Green and Fidell (1991) later applied this model to an expanded data set developed by Fidell *et al.* (1991), quantifying the influences of nonacoustic factors on annoyance reports. Harris (Finegold *et al.*, 1994) omitted selected points from the latter data set to derive an ogival fitting function in place of the quadratic form of Fidell *et al.* (1991). CHABA (Fidell, 1996) eventually identified fitting functions for community reaction to high-energy impulsive sounds, while Miedema and Vos (1998) argued for three separate quadratic functions (to fit data from rail, road, and air traffic) in place of a single generalized function for all transportation noise.

IV. PRACTICAL IMPORTANCE OF DOSAGE-EFFECT RELATIONSHIPS IN COMMUNITY NOISE ASSESSMENTS

The U.S. Federal Interagency Committee on Noise (FICON) declared in its 1992 report that annoyance was its preferred ''summary measure of the general adverse reaction of people to noise,'' and that ''the percentage of the area population characterized as 'highly annoyed' by long-term exposure to noise'' was its preferred measure of annoyance. FICON institutionalized the fitting function developed by Harris (*cf.* Fig. 5) for the U.S. Air Force as its preferred dosage-effect relationship. FICON also indicated in Section 3.3.1.2 of its 1992 report that ''the DNL methodology'' (i.e., its preferred dosage-effect relationship) was the basis for its judgments about the acceptability of noise exposure, as expressed in the agency's ''land use compatibility''[6] recommendations.

The canon of community noise policy of U.S. federal agencies is based on FICON's endorsements (1) of annoyance as the primary measure of community reaction[7] to noise exposure, (2) of a particular fitting function as a means for predicting annoyance from cumulative exposure, and (3) of a set of guidelines for the acceptability of annoyance prevalence rates, expressed as ''land use compatibility'' recommendations. Thus, decisions about the award of billions of dollars of federal subsidies to construct airport and highway infrastructure and to mitigate their noise impacts ostensibly rest on the shape of a purely descriptive fitting function,

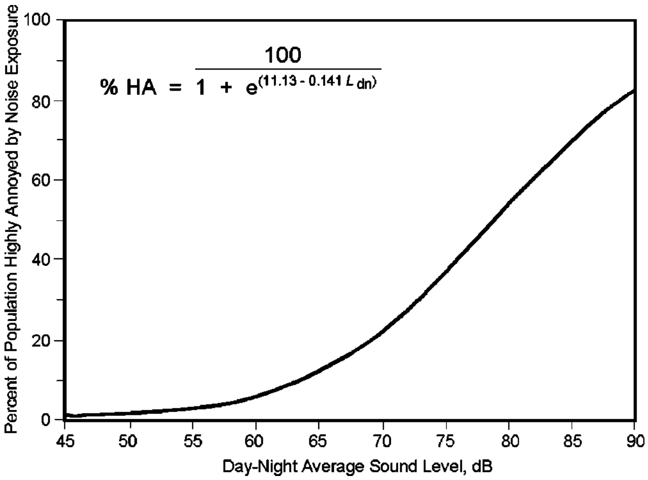

FIG. 5. Fitting function adopted by FICON (1992) as a dosage-effect relationship.

unsupported by quantitative, theory-based, or other systematic understanding of the origins and mechanisms of community reaction to transportation noise.[8]

V. PRAGMATIC LIMITATIONS OF DOSAGE-EFFECT ANALYSIS

Because the dosage-effect relationship seen in Fig. 5 lacks pronounced inflection points, it is not self-interpreting for policy purposes. The slope of the curve varies smoothly from about 1% to 3% highly annoyed per decibel of noise exposure throughout its range, such that the curve itself does not strongly constrain the choice of policy points for regulatory purposes. Historically, such policy points have been identified at 5-dB intervals, in tacit recognition of the uncertainty of measurements of both noise exposure and community reaction. Definition of any particular value of noise exposure as a ‘‘significant’’ noise impact is thus inescapably arbitrary, and must be made on nontechnical grounds. At $L_{\mathrm{dn}} = 65\,\mathrm{dB}$, the FICON curve seen in Fig. 5 predicts an annoyance prevalence rate of 12.3%, a less than self-evident definition of significance.

Several aspects of FICON’s dosage-effect relationship and its application to regulatory policy regularly attract critical comment, even though controversy over its manner of creation has largely subsided. A common criticism of the relationship is that it demonstrably underestimates the prevalence of annoyance due to aircraft noise. Part of this underestimation is due to the functional form of the relationship, and to the range of exposure values over which the relationship was developed. Another source of underestimation is its lack of source-specificity.

The segment of a third-order polynomial fitting function identified by Schultz (1978) was suitable for evaluation only within a restricted range of commonly encountered transportation noise exposure values. The ogival form of the FICON relationship was favored in part for its asymptotic behavior at low and high exposure levels, and in part to control where the broad knee of the curve lies on the abscissa. It is not clear, however, that regulatory policy analyses are as well served by the ogival form of the fitting function as was initially hoped.

The composition and character of community noise differ greatly throughout the enormous (>40 dB) range of exposure levels from which FICON’s relationship is derived. In quiet, low population density residential settings, community noise exposure may be governed by relatively small numbers of low level, individually identifiable, discrete noise events that are produced by small numbers of sources. In high-density urban settings, noise exposure is generally created by larger numbers of temporally overlapping, higher level noise events (Fidell *et al.*, 1981). Developing a dosage-effect relationship over this entire range, rather than from data in the vicinity of potential policy points (that is, round-numbered DNL values at which regulatory agencies consider certain actions justifiable), implies a belief that the same processes that give rise to annoyance in quiet rural and suburban settings also give rise to annoyance in noisy urban settings such as those adjacent to airport runways.

The ‘‘equal energy hypothesis’’—the notion that the effects of number, duration, and level of noise events are completely equivalent and interchangeable determinants of the annoyance of noise exposure—provides the rationale for including information about community reactions to extremely low and extremely high levels of noise exposure from all sources in a single dosage-effect analysis. Although evidence exists to support the plausibility of the hypothesis, counter-evidence also exists about the unequal influences on annoyance of maximum levels and numbers of noise events.[9] It is for reasons of expedience rather than any conclusive demonstration of causality that DNL intentionally combines into a single index (and thus confounds) all of the primary physical characteristics of noise events that could arguably cause noise-induced annoyance.

The shape of FICON’s fitting function is strongly affected by reactions of communities exposed to transportation noise at extreme levels about 20 dB higher and lower than those of practical regulatory interest. Why should a curve intended to inform decisions about tolerable levels of annoyance in common circumstances of noise exposure so strongly reflect information about reactions observed in communities with highly atypical exposure? There can be no realistic expectation that noise-induced annoyance in high population density, motorized society can be limited to that of quiet rural areas, nor that residential uses can freely be made of lands exposed every few minutes, night and day, to high levels of aircraft noise. Forcing the ogival form of FICON’s fitting function through the high noise exposure data effectively depresses the broad knee of the curve at more moderate exposure values. This in turn biases the function toward underestimation of the prevalence of annoyance at more commonly occurring exposure levels.[10]

This effect is readily apparent in comparing the means of measured annoyance prevalence rates to the FICON curve in adjacent exposure ranges of practical interest. Figure 6 shows an expanded view of annoyance prevalence rates with aircraft noise exposure levels in the vicinity of $L_{\mathrm{dn}} = 65\,\mathrm{dB}$. These data are those of Green and Fidell (1991), supplemented by the findings of subsequent opinion surveys. The

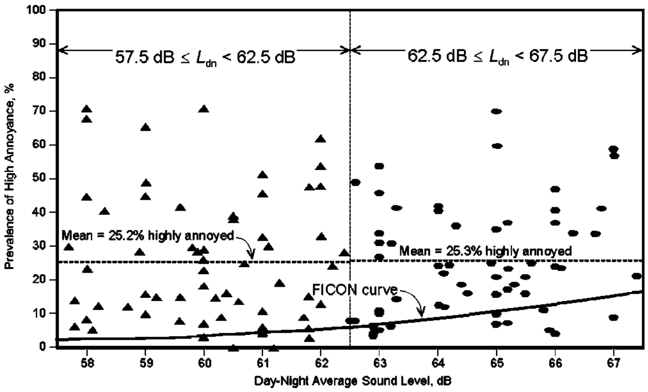

FIG. 6. Expanded view of data on prevalence of aircraft noise-induced annoyance in the vicinity of $L_{dn}=60$ and 65 dB.

triangular data points on the left-hand side of the figure represent observations of the prevalence of annoyance due to aircraft noise in the range of $57.5\,\text{dB} \leqslant L_{dn} < 62.5\,\text{dB}$, while the oval data points on the right-hand side represent observations of the prevalence of annoyance due to aircraft noise in the range of $62.5\,\text{dB} \leqslant L_{dn} < 67.5\,\text{dB}$. The two sets of data points thus represent ranges of ±2.5 dB around the pragmatically important exposure values of $L_{dn}=60$ and 65 dB, respectively.

The dashed horizontal lines in the lowermost panel of Fig. 6 show the means of the field observations. The curved line is the FICON relationship. It is readily apparent (1) that the FICON relationship underestimates the prevalence of field measurements aircraft noise-induced annoyance, and (2) that the aircraft annoyance data themselves do not compel identification of a DNL value of 65 dB as a self-evidently justifiable or data-driven policy point.

VI. INTERPRETABILITY OF DOSAGE-EFFECT RELATIONSHIPS FOR POLICY PURPOSES

In hindsight, the purely descriptive and exclusively acoustic approach to the problem of predicting community reaction to noise that Schultz pioneered has not been as much of a panacea as once hoped, because the resulting relationships fail to take into account or explain the great variability of community reaction. A less than compelling dosage-effect relationship provides the appearance but not the substance of a systematic basis for policy interpretations which in reality reflect the charters and interests of regulatory agencies at least as much as information about actual noise effects.

A dosage-effect relationship implies that variation in whatever quantity is plotted as the independent variable on the abscissa *causes* variation in whatever quantity is plotted as the dependent variable on the ordinate. When the independent variable is merely an expedient one (such as cumulative noise exposure, an adventitious measure devised for other purposes), and when there is good reason to believe that the dependent variable is strongly influenced by other factors as well, the persuasiveness and utility of a dosage-effect relationship are open to question.

Many of the limitations of the work inspired by Schultz's 1978 relationship stem from its noncausal nature. The most obvious deficiency of the many curve-fitting exercises that followed Schultz's is that none accounts for the better part of the variance in what is now a very large body of social survey data on the prevalence of annoyance associated with environmental noise exposure. This means that no systematic explanations are available for large differences in annoyance prevalence rates in different communities with the same noise exposure. It also means that accurate predictions of the prevalence of annoyance in communities exposed to change in noise levels (for example, from increases in air traffic due to increased market demand, a favorable regulatory climate, over-building of airport infrastructure, or other causes) remain elusive. It further means that prediction of the benefits of costly measures intended to mitigate noise exposure cannot be made with confidence, and that regulatory policies intended to balance conflicting societal interests remain largely arbitrary and poorly supported by technical analysis (Fidell, 1999).

VII. CONSEQUENCES OF FICON'S ENDORSEMENT OF A PREFERRED METHODOLOGY FOR PREDICTION OF COMMUNITY REACTION TO NOISE

FICON'S endorsement of the prevalence of a consequential degree of annoyance as the primary (and for practical purposes, sole) measure of community reaction to noise, and of a particular dosage-effect relationship between noise exposure and annoyance, has undeniably simplified the process of estimating and disclosing transportation noise impacts as mandated by the U.S. National Environmental Policy Act of 1969. This approach errs on the side of oversimplification of the process of predicting community reaction to transportation noise, since (1) noise exposure is neither a necessary nor a sufficient antecedent condition for annoyance, and (2) noise exposure *per se* is not a particularly effective predictor of the prevalence of annoyance. A recent summary by Schomer (2002) has catalogued the various ''adjustments,'' ''corrections,'' and ''normalizations'' to DNL that have been suggested to improve the accuracy of prediction of community reaction from noise exposure measurements. Suggesting *ad hoc* adjustments to exposure measurements construes the problem as one of measurement rather than one of theory, however, and thereby treats the symptoms rather than the disease. Bandaids applied to exposure measurements are akin to the epicycles that Ptolemy's views about the orbits of planets required to account for their otherwise inexplicable retrograde motions. Such patchwork solutions appear helpful in the short run, but only postpone development of more systematic and fundamental explanations.

In the United States, FICON's doctrine has codified the *status quo* in understanding of community reaction to noise as of a quarter century ago, led to repeated misprediction of community reaction to noise exposure, and generally reinforced policies that do not accomplish their own goals. A greater proportion of the population than predicted by FICON is demonstrably highly annoyed by aircraft noise at the *de facto* threshold of federal concern ($L_{dn}=65\,\text{dB}$) (Miedema and Vos, 1998); many airport noise controversies remain inexplicable from the perspective of official recommendations of compatible land use; and vigorous opposition to construction of airport infrastructure is more the rule than the exception.

Overreliance on officially predicted annoyance prevalence rates to assess community reaction to aircraft noise has also created an institutional disconnect between local and federal perspectives. For all practical federal purposes, ‘‘community reaction to noise’’ means little more than an annoyance prevalence rate estimated by an assumption-laden fitting function. In the daily experience of airport proprietors and local governments, however, ‘‘community reaction’’ generally refers to numbers of recent noise complaints. Imprecise predictions of prevalence rates of covert attitudes have in effect taken precedence over the overt behaviors that were the original focus of Rosenblith *et al.*, and which remain the crux of many aircraft noise controversies.[11]

VIII. ALTERNATIVES FOR IMPROVING ASSESSMENT OF COMMUNITY REACTION TO AIRCRAFT NOISE

According to FICON (1992), Green and Fidell (1991) ‘‘demonstrated how the variability in the data points of the Schultz curve could be significantly reduced by assuming that citizens of the same community tend to share common criteria for deciding when an intruding noise is ‘highly annoying’.’’ Systematic consideration of the aggregate effect of nonacoustic factors on self-reported annoyance can indeed improve the accuracy and precision of predictions of annoyance prevalence rates. FICON also noted in its 1992 report that ‘‘This work is continuing and may provide a basis for an improved understanding of community response to noise.’’ In the decade since publication of FICON’s report, however, its successor agency, FICAN, has taken no major action to further improve the accuracy of prediction of the prevalence of noise-induced annoyance in communities.

Furthermore, land use compatibility recommendations (notionally linked to dosage-effect analysis, which in turn relies on cumulative noise exposure as a sole predictor variable) have effectively displaced all other interpretations of transportation noise effects for federal purposes.[12] In particular, FICON (1992) rejects complaint behavior as a basis for interpreting noise effects on the grounds that ‘‘Annoyance can exist without complaints and, conversely, complaints may exist without high levels of annoyance.’’ As Schultz and his successors have amply demonstrated, however, it is equally true that high levels of annoyance can exist at low levels of noise exposure, and low levels of annoyance can exist at high levels of noise exposure. The lack of a strong or simple relationship between noise exposure and its effects is neither a consistent nor a persuasive rationale for ignoring noise complaints in policy analyses.

In fact, annoyance prevalence rates and complaint rates may be usefully viewed as two sides of the same coin. Annoyance prevalence rates are estimated from systematically solicited opinions about noise. Complaints are spontaneous (unsolicited) reports of adverse opinions about noise. Complaints and annoyance may differ in gestation period, but understanding of the time course of arousal and decay of annoyance is so imprecise that nothing definitive is known about the terms of exposure that give rise to either annoyance or complaints.

Questionnaire items soliciting self-evaluations of degrees of annoyance necessarily focus on the long term, because it is impractical to administer a social survey in real time to a representative sample of a community about reactions to individual aircraft noise events. Spontaneous self-reports about reactions to aircraft noise often concern egregious individual noise events or periods of exposure. Airports seldom receive complaints on New Year’s eve about annual average exposure levels over the course of the preceding calendar year.

In this context, it makes no more sense to ignore complaint behavior because it may or may not be closely related to annoyance than to ignore attitudes of annoyance because they may or may not be closely related to complaints. Both solicited and unsolicited forms of self-report confound ‘‘true’’ sensitivity to noise with reporting bias (Green and Fidell, 1991). Biases associated with complaints may strike some as more obvious than biases associated with self-reported annoyance, but neither spontaneous nor solicited forms of expression are free from nonacoustic influences. Neither complaints nor annoyance are any less worthy of consideration because of this confounding, and neither the acoustic nor the nonacoustic determinants of annoyance and complaints can be summarily dismissed by airport proprietors or regulatory agencies.[13]

In reality, noise complaints play a strong, albeit unspoken, role in airport design and operation. Dallas–Ft. Worth International Airport was sited on about 18 000 acres of land in the early 1970s, even though its projected $L_{\mathrm{dn}}=65$ dB cumulative noise exposure contour encompassed far less area. Likewise, Denver International Airport was sited on about 29 000 acres, even though its projected $L_{\mathrm{dn}}=65$ dB cumulative noise exposure contour was considerably smaller. Both of these greenfield airports have nonetheless attracted tens of thousands of aircraft noise complaints over the years, some from communities many miles from their $L_{\mathrm{dn}}=65$ dB cumulative noise exposure contours. Regional airspace use and flight track modification controversies such as the Extended East Coast Plan are typically complaint-driven, and frequently require resolution of noise problems at exposure levels that are inconsequential from the perspective of federal land use compatibility guidelines. Although such adverse community reaction may seem ‘‘wrong’’ from the perspective of airport proprietors and regulators, it nonetheless has substantive consequences and obvious implications for the adequacy of cumulative exposure as a sole predictor of community reaction.

Complaints were abandoned as a measure of community reaction to noise at the federal level in the 1970s largely because of the promise that Schultz’s relationship seemed to offer. At the time, noise complaints were difficult to process and systematically compare, largely inaccessible to researchers, and generally awkward to interpret. These limitations have lessened over the last decade as computer-based aircraft noise and operations monitoring systems have become commonplace at major airports, and as geo-information system

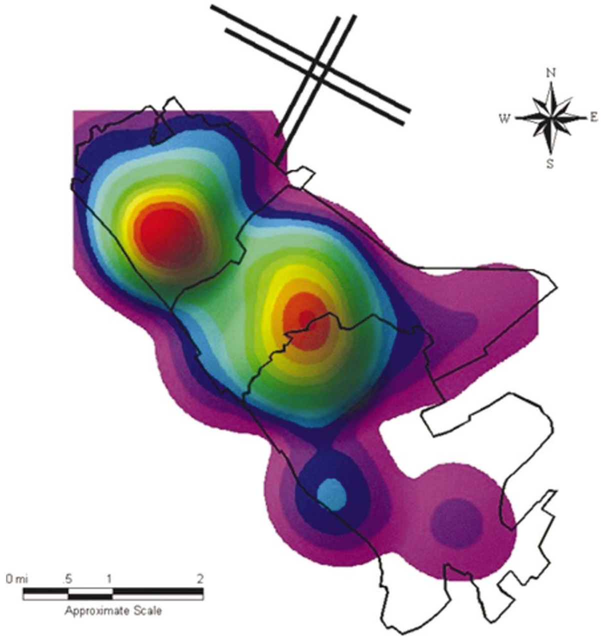

FIG. 7. Rendering of complaint density pseudo-terrain as redundantly color-coded false elevation behind main departure runways at San Francisco International Airport.

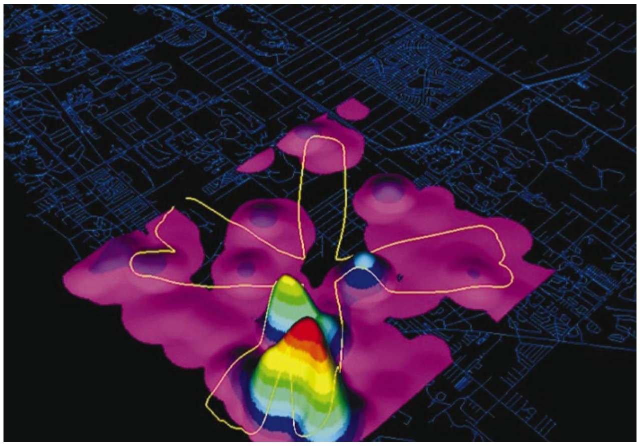

FIG. 8. Rendering of complaint density pseudo-terrain as redundantly color-coded false elevation near Naples Municipal Airport, with 95 dB maximum A-weighted aircraft noise contour superimposed in yellow.

software has come of age. Larger airports now routinely maintain well-organized, long-term files of geo-coded noise complaints. These are proving more tractable to interpretation than previously believed (Fidell and Howe, 1998).

Perhaps the most common remaining complaints about complaints as a measure of community reaction to noise are (1) that they are not obviously related to cumulative noise exposure, and (2) that most aircraft noise complaints are received from geographic areas outside the $L_{\mathrm{dn}} = 65\,\mathrm{dB}$ noise exposure contour at most airports (GAO, 2000). These circular concerns are misplaced, given that cumulative noise exposure is itself a far from perfect predictor of annoyance. Complaint rates are sometimes also denigrated as emphasizing the views of small numbers of frequent complainants, even though analysis of very large, computer-maintained aircraft noise complaint files shows that mean and modal numbers of complaints per complainant are quite small (Fidell and Howe, 1998).

One example of the ready interpretability of complaint information is evident in the geographic pattern of noise complaints associated with start of takeoff roll noise at San Francisco International Airport. An airport-sponsored analysis (Pearsons *et al.*, 2000) of noise complaints lodged over a period of 6 years was conducted by geo-coding street addresses of complainants to contour complaint densities. Figure 7 shows these complaint densities coded as false elevation. The peaks of the pseudo-terrain correspond to two concentrations of complaints, located behind and roughly 45° to the sides of the extended centerlines of the airport's primary departure runways. These locations correspond to the lobes of the directivity patterns of jet engine exhaust noise of aircraft departing on these runways. The complaint concentrations are well beyond the airport's $L_{\mathrm{dn}} = 65\,\mathrm{dB}$ cumulative noise exposure contour.

The unusually great low-frequency content of start of takeoff roll (''backblast'') noise is an arguably special case in which the degree of adverse reaction to noise is underestimated by the A-weighting of cumulative exposure (cf. Fidell *et al.*, 2002). Limitations of the A-weighting network do not account for similar findings about the geographic distribution of complaints with respect to DNL contours at airports elsewhere, however. An airport-sponsored complaint analysis conducted at Naples Municipal Airport in Florida documents a mismatch between overt community reaction to aircraft noise and land use compatibility recommendations premised on annoyance prevalence rates. Figure 8 shows two ''mountains'' in complaint density (rendered as false elevation) along the extended centerline of the primary departure runway at the airport. The contour draped over the complaint density pseudo-terrain that encompasses the bulk of the high ground is the 95 dB maximum A-level contour. (The airport's $L_{\mathrm{dn}} = 65\,\mathrm{dB}$ contour closes much nearer to the end of the runway.)

Noise complaints at Naples Municipal Airport were dominated by a very small number of unscheduled operations by an unusually noisy aircraft. Noise emissions from the fleet operating at Hanscom Field, however, are less influenced by such small numbers of operations of especially

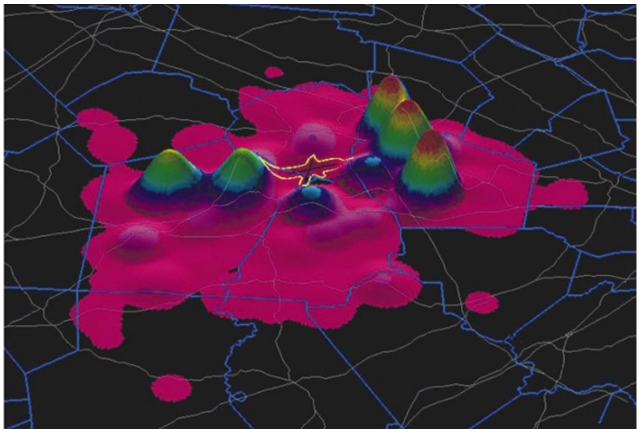

FIG. 9. Rendering of complaint density pseudo-terrain as redundantly color-coded false elevation near Hanscom Field, with $L_{\mathrm{dn}} = 65\,\mathrm{dB}$ noise exposure contour superimposed in yellow.

noisy aircraft. Nonetheless, Fig. 9 shows that peaks of complaint density remain well outside of the $L_{\mathrm{dn}}=65$ dB contour that supposedly distinguishes airport-compatible from airport-incompatible residential land uses.

The geographic distributions of noise complaints with respect to runway ends, flight tracks, and directivity of aircraft noise sources are more consistent with proximity to flight tracks and directivity of noise sources than with current regulatory policy for assessment of transportation noise impacts. The increased interpretability of noise complaints made possible by computer-based record keeping and geoinformation system software suggests a more prominent role in the future for complaint rate information in the design of aircraft noise mitigation projects and impact assessments. Ironically, such a role would be reiminiscent of that which complaints played in community reaction assessments prior to Schultz's 1978 synthesis work.

IX. CONCLUSIONS

A quarter of a century of follow-up work to Schultz's 1978 synthesis is sometimes cited as establishing credibility for assessment of environmental noise impacts exclusively on the basis of DNL values. It is apparent in retrospect, however, that a point of diminishing returns has been passed in dosage-effect analysis, and that the impetus to research and policy analysis that Schultz's work provided has run its course without yielding further major improvements in systematic understanding of causes and mechanisms of community reaction to transportation noise. An administratively convenient partial solution to a vexing societal problem may suffice for some nontechnical policy purposes. Expedient but incomplete solutions do not constitute genuine understanding of community reaction to noise, however, and can not serve in lieu of theory development and research to improve understanding in this field.

A thorough review of the technical rationale for FICON's decade-old endorsement of dosage-effect analysis would be a useful initial step toward improved understanding of community reaction to transportation noise. The following issues are among those that warrant scrutiny in light of what has been learned since Schultz's 1978 work:

(i) the effects on policy analyses of poor correlation between annoyance prevalence rates predicted by the fitting function preferred by FICON and rates actually observed in communities;
(ii) analysis of the logic and effects on noise impact interpretations of the range of exposure values over which the fitting function is developed, and of its form;
(iii) computation of error bounds and confidence intervals for predicted annoyance prevalence rates, and frank exploration of their effects on land use compatibility recommendations;
(iv) adoption of a data-driven rationale for selection of policy points rather than an imprecise predictive function;
(v) systematic, quantitative, and theory-based consideration of nonacoustic factors as codeterminants of the annoyance of transportation noise; and
(vi) formal recognition of geographic distributions of noise complaints as an alternate indication of actual community reaction to transportation noise.

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[1] The first urban noise survey (Fletcher *et al.*, 1930) had been conducted in New York City three decades earlier, not long after the development of portable electronic sound measurement instruments made such work possible. Societal interest in environmental noise effects remained minimal through the intervening decades of economic depression and world war, however.

[2] The reasoning that led to EPA's embrace of DNL is described in great detail by von Gierke (1973) in supplementary reports prepared in support of the Levels Document.

[3] The U.S. Air Force later developed a set of numeric equivalents for the original CNR letter categories A though M (Stevens and Pietrasanta, 1957), in which the equivalent level of the 300–600 Hz octave band of aircraft noise was substituted for the original ''level rank'' curves. (This spectral region is a reasonable predictor of the ability of aircraft noise to interfere with speech.) The final development of this ''Composite Noise Rating'' by Galloway and Pietrasanta (1963) substituted perceived noise levels for equivalent levels in the 300–600 Hz octave band. A CNR value of 100 is equivalent to $L_{\mathrm{dn}}=65$ dB. By the early 1970s, the Composite Noise Rating scale had evolved into the ''Noise Exposure Forecast'' (NEF) scale in which the earliest aircraft noise exposure contours were expressed.

[4] The initially controversial nature of characterizing community reaction to noise in terms of annoyance is apparent from written comments by the Boeing Commercial Airplane Group (von Gierke, 1973, p. III-C-18): ''The selection of 60 dBA as a goal appears to be founded on arbitrary conclusions about the relationship between cumulative noise exposure and the highly subjective concept of 'public annoyance'.'' The ''subjective'' nature of annoyance still grates on some who regret that people do not respond to noise exactly as do sound level meters. If Schultz's work has accomplished nothing else, it has demonstrated the futility of attempts to treat community reaction to noise as an exclusively physical process.

[5] Taking a normative rather than a descriptive approach, Fidell *et al.* (1988) hypothesized that the shape of a dosage-effect relationship should be governed by the rate of increase of annoyance with effective (duration-adjusted) loudness. They also attributed deviations from the hypothesized rate of growth of annoyance to the effects of nonacoustic factors. These nonacoustic factors translate (''bias'') the prediction function along the abscissa, but do not alter its form or shape.

[6] It is important to recall that the asset that ''land use compatibility'' guidelines protect is public investment in airport facilities. Surrounding land uses are defined as compatible with an airport when they do not jeopardize or constrain the airport's continued operation and expansion.

[7] Since the goal of assessing community reaction to noise exposure changed from predicting overt group action to annoyance prevalence rates, the term has become something of a misnomer. ''Community reaction'' today means little more than a prevalence rate of a consequential degree of annoyance among individuals.

[8] Decisions about the conduct of large civil works projects are of course influenced to a greater degree by political, economic, and pragmatic considerations than by their noise impacts. Nonetheless, challenges to such projects based on state and federal environmental disclosure statutes often turn on issues of noise policy and interpretation. Thus, the lack of explicit or systematic linkage between FICON's fitting function and its policy interpretations of ''land use compatibility'' guidelines underscores the arbitrariness of such recommendations.

[9] Exposure, the logarithmic sum of numbers and levels of individual noise events (commonly normalized to 1-s durations), is obviously highly correlated with both numbers and levels of noise events. Given this high correlation, as well as the influences of inevitable nuisance variables, a critical

experiment to determine whether numbers of noise events, levels of noise events, or their product are more closely related to the prevalence of annoyance would require unreasonably large sample sizes and precision of measurement.

[10] The parabolic fit of Miedema and Vos (1998) more closely reflects the mean annoyance prevalence rate for aircraft noise in the vicinity of $L_{\mathrm{dn}} = 65$ dB, but, like the FICON curve, fails to account for the better part of the variance in the data set.

[11] A large part of the rationale for reducing the 1981 budget of EPA's Office of Noise Abatement and Control to zero was that, like politics, noise controversies are inherently local (Shapiro, 1991). This rationale is inconsistent, however, with the preemptive disconnect between federal and local perspectives on transportation noise impacts.

[12] FICON acknowledges in principle the limited utility of noise metrics such as integrated time in excess of a threshold level and maximum sound level for supplementary analytic purposes, but expresses its formal interpretations of "land use compatibility" only in terms of cumulative exposure.

[13] Some argue that complaints ought not inform regulatory decisions because small numbers of them could have disproportionate influence on such decisions. Given that a subjective judgment about the "significance" of noise exposure is *not* a scientific nor a technically justifiable decision in the first place, there is no technical basis for determining whether the virtues of representative sampling (in the case of quantifying the long-term attitude of annoyance) outweigh the value to public officials of spontaneous reports by their constituents of adverse reactions to noise (in the case of the immediate behavior of complaining).

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