A Quick Introduction to Risk-Informed Interference Assessment

The Spectrum and Receiver Performance Working Group
of the
Federal Communications Commission's
Technological Advisory Council

Version 1.00, April 1, 2015

Executive Summary

In judging whether to allow new service rules, the FCC has to balance the interests of incumbents, new entrants and the public. The trade-off between the benefits of a new service and the risks to incumbents has to date been essentially qualitative. This short paper proposes the use of quantitative risk analysis to assess the harm that may be caused by changes in radio service rules.

Risk analysis considers the likelihood-consequence combinations for multiple hazard scenarios, and complements a "worst case" analysis that considers the single scenario with the most severe consequence, regardless of its likelihood. Risk-informed interference assessment is the systematic, quantitative analysis of interference hazards caused by the interaction between radio systems. Such an assessment has three major steps:

1. Make an inventory of all significant harmful interference hazard modes.
2. Define a consequence metric to characterize the severity of hazards.
3. Assess the likelihood and consequence of each hazard mode.

Quantitative risk assessment can:

- provide a common currency for comparing different interference scenarios and assessments;
- enhance the completeness of analysis and increase the chances of identifying unexpected harmful interference mechanisms;
- provide objective information to policy decision makers balancing the benefits of a new service and its adverse technical impact on incumbents.

Implementing quantitative risk assessment requires a change in culture, and will take time. The FCC should therefore start small, but start soon:

- Develop know-how in the agency and the wider community by a lecture series on modern risk management, and by adding courses on statistics and risk-management to the FCC University curriculum.
- Use quantitative risk assessment in its own work, and publish the analyses and results.
- Provide quantitative guidelines on unquestionably acceptable and unacceptable interference risks, respectively, e.g. as likelihood-consequence regions on a risk chart.
- Pilot this approach in selected site-specific license waiver proceedings.

We are not able in life to avoid risk but only to choose between risks.

—Stanley Kaplan & John Garrick

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1. Background

Freeway signs that promote state lotteries proclaim the possible amount one could win; they don't disclose the probability of actually taking home the jackpot. Most harmful interference claims work the same way. Incumbent services fearing harm from new entrants often emphasize the catastrophic consequences of extreme interference events, but not their low likelihood.

In judging whether to allow new service rules, the FCC has to balance the interests of incumbents, new entrants and the public. The trade-off between the benefits of a new service and the risks to incumbents to date has been essentially qualitative. This paper makes a case for quantitative risk assessments that broaden regulatory analysis from "What's the worst that can happen?" to "What can happen, how likely is it, and what are the consequences?" and can thus provide a stronger evidence base for policy judgments.

The FCC's Technological Advisory Council ("TAC") is a formal advisory committee established under the Federal Advisory Committee Act. For its work in calendar year 2014, the Spectrum and Receiver Performance Working Group ("the working group") was asked to "make recommendations about the use of statistical methods and metrics in the formulation of rules and analysis of harmful interference." The working group adopted the following mission: "To help the FCC, and the spectrum community at large, find additional, quantitative ways to reason about the risks of harmful interference due to changes in radio service rules, e.g. new allocations, rule changes, and waivers."

This briefing paper outlines the use of quantitative risk analysis to assess the potential harm that may be caused by changes in radio service rules. It is based on the deliberations of the working group.[1]

[1] The working group studied this topic through weekly teleconferences, regular exchanges of documents reflecting those discussions and on-going analyses, and in-person, quarterly gatherings immediately before each official meeting of the TAC. The group was informed by a variety of resources and working papers covering, among other things, the work of standards groups such as 3GPP, ANSI, ISO and TIA/EIA; the use of statistical interference metrics by FCC; risk-informed regulation as practiced by the Nuclear Regulatory Commission; an analysis of pro forma interference scenarios; a review of statistical simulation methods used in the wireless engineering community, e.g. Monte Carlo modeling; a review of cases where the FCC pushed back against worst case analysis; and a study of applications for

The working group focused on the assessment of harmful interference during rulemaking, leaving aside other activities such as adjudication and enforcement. It focused on estimating risk from an engineering perspective. It did not address cost/benefit trade-offs which, although an essential part of regulatory decisions, fall outside the group's engineering remit. That said, quantitative risk assessment should assist trade-off calculations by helping to quantify expected costs.

The assessment of the likelihood and consequences of harmful interference will always rely on expert judgment and cannot be entirely quantitative; the assumptions informing a model and the interpretation of results can always be debated. The group recognized that engineering analysis is constrained by the legal and economic context, and that technical analysis influences legal and economic assumptions; it did not analyze these inter-relationships. However, *risk-informed decision-making*—an approach to regulatory decision-making in which insights from quantitative risk assessment are considered along with the public interest, economic analysis and other engineering insights—will lead to more productive use of spectrum assets.

The approach described here is a complement to the customary and well-established "worst case" analysis, which can be defined as an assessment of interference potential that focuses on a single, high impact scenario where most if not all parameters take extreme values.

2. Risk Definitions

Following ISO/IEC 31010 (2009), the international standard for risk assessment techniques, we posit that "the *purpose of risk assessment* is to provide evidence-based information and analysis to make informed decisions on how to treat particular risks and how to select between options"; in the spectrum management case, the risk is that of harmful interference and the selection is between various possible service rules.

We define *risk* as the combination of likelihood and consequence for multiple failure scenarios, inspired by the "risk triplet" introduced by Kaplan & Garrick (1981): What can go wrong? How likely is it? What are the consequences? By contrast, a so-called worst case analysis focuses on the single scenario with most severe consequence, regardless of its likelihood.

Quantitative risk assessment sets out to answer these three questions by using numerical estimates of frequencies and consequences to calculate risk systematically. Quantitative assessments are necessary to compensate for poor human intuition regarding probability and statistics.

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waivers, special temporary authority and experimental licenses to identify areas where risk-based interference analysis could be piloted.

To quote Michael Blastland and David Spiegelhalter (2014, p. 84):

> We don't 'see' odds – how likely the thing is – we 'see' consequences. That's what people would mean if they were to say 'picture the risk'. They mean picture the worst that can happen.

Risk-informed interference assessment, in turn, is a systematic, quantitative analysis of the likelihood and consequence of interference hazards caused by the interaction between radio systems, especially incumbent and prospective radio services. Such an assessment has the following major components, discussed in more detail below:

- An inventory of all significant harmful interference hazard modes.
- The determination of a consequence metric to characterize the severity of hazards in a uniform way.
- An assessment of likelihood and consequence for each hazard mode.

The assessment would be informed by the FCC's policy on what risks are acceptable, i.e. which combinations of likelihood and consequence should be considered harmful or not.

3. Quantitative Analysis of Interference Risk

A. Factors affecting Interference

There are many causes and consequences of radio frequency ("RF") interference. The interaction between two radio systems is affected, among other things, by the locations of the interfering and affected systems, the characteristics of the transmitters and receivers of the two systems, and the coupling between them due to factors like antenna gain patterns and propagation loss. A quantitative risk assessment also has to define consequence metrics that assess service degradation, and estimate the likelihood of these hazards occurring. These factors are summarized in Figure 1.

There are usually multiple interference scenarios. For example, both Out-of-Band Emissions ("OOBE": interfering signals leaking into the affected system's operating channel from transmissions in an adjacent channel) and Adjacent Band Interference ("ABI": a service being influenced by energy entirely contained within an adjacent band that its receiver cannot reject) can lead to service degradation. There are also a variety of co-channel interference hazards, ranging from unintentional radiators to maliciously operated transmitters. There may also be both single-source interference from a strong transmitter and/or aggregate interference from a large number of individually weak transmitters.

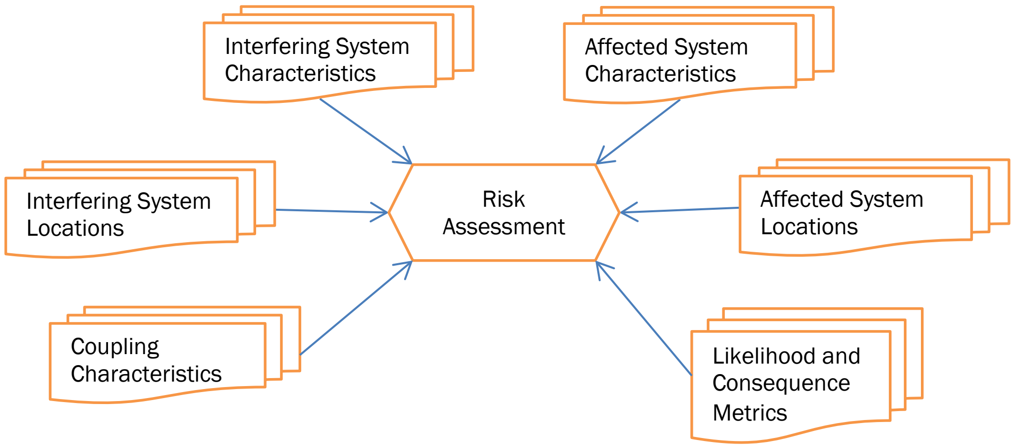


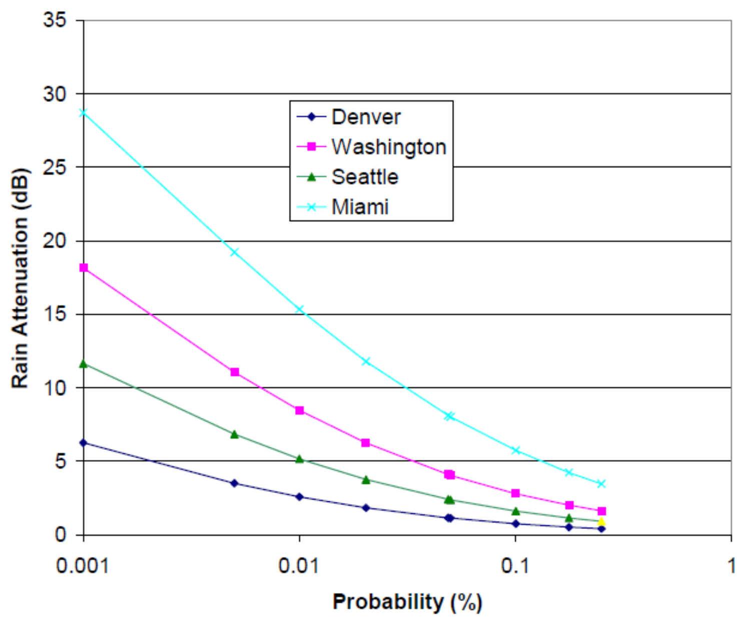
Figure 1. A Simplified Representation of the Parameters and Process Needed to Perform an Interference Estimation

For example, interference between cellular handsets and TV receivers in adjacent channels depends on variety of factors, some of which are listed in Table 1.

Table 1. Parameters affecting interference between cellular handsets and TV receivers operating in adjacent channels

The level of received TV signal received, which depends on the power of the transmitter and the distance to the receiver.
The quality of the TV signal, which depends on path it has followed from the transmitter to the receiver.
The varying sensitivity of different TV receivers to an interfering cellular signal in a nearby channel, which depends on receiver design.
The percentage of households tuned to affected TV channel rather than others further away in frequency from the cellular signal.
The type and bandwidth of the cellular signal.
The strength of the interfering signal transmitted by the handset in its allocated channel, which is influenced by its distance to its base station.
The amount of signal that the handset leaks into the TV channel, which depends on handset design.
The amount of time a handset transmits in the most adjacent channel, which depends on the cellular system's channel assignment algorithm.
The coupling loss between TV receiver and the handset transmitter, which depends on relative antenna orientations, distance, and path loss.
Source: Working group discussions

Parameters affecting interference take on a range of values, and are often independent. For example, Figure 2 shows the rain attenuation probability distributions at various locations according to the MITRE (2001) study of interference from a multi-channel video distribution and data service ("MVDDS") into direct broadcast satellite ("DBS") television receivers (aka the "Northpoint case").



Source: MITRE (2001), Figure 2-1

Figure 2. Rain model results for representative DBS locations.

Selecting single values, often extreme "worst case" values, is not representative of actual risk. Indeed, tailoring rules to avoid very severe but highly unlikely interference can lead to unnecessarily wide guard bands and low transmit power that prevent the full potential of spectrum use to both incumbents and new services from being realized.

B. Method

The first step in quantitative risk assessment is to make an inventory of all expected hazards—harmful interference scenarios in the spectrum case—such as co-channel interference, adjacent band interference (including overload, blocking, intermodulation and spurious emissions) and out-of-band emissions from adjacent channels.

The next step is to estimate the likelihood and consequence of each of these hazards, given the operational parameters that affect interference (see for example Table 1), deployments and operating rules.

Likelihood is relatively straightforward: it is the probability of occurrence of a hazard. Some care is needed in specifying the universe of measurements; for the purposes of regulatory decisions an appropriate population might well be all affected receivers.

A consequence metric of the severity of interference can be defined in many ways, from monetary impact (e.g. reduction in a service provider's profit) and service metrics (e.g. time period or percentage that a TV service is unavailable, bit error rates for mobile data services, or range reduction for radar systems) to RF metrics (e.g. probability that interfering power exceeds, or signal-to-noise ratio falls below, a threshold). Specific communities may have long-established RF metrics (e.g. I/N degradation in radar and satellite services), but may need to provide mappings between those values and actual service degradation when asserting harm from other services.

For example, MITRE developed several interference impact criteria in its analysis of interference from MVDDS services into satellite television receivers (the Northpoint case): three metrics of the absolute or relative increase in DBS downlink unavailability, and the minimum clear-air value of (C/I_M), where C is the weakest DBS downlink power level and I_M is the MVDDS-interference power level at the output of a DBS receiving antenna (MITRE, 2001, section 5.1.1).

The likelihood and consequence of hazards are often plotted on a risk chart; a generic version is shown in Figure 3. High risk hazards are in the top right hand corner, shown in red; they have severe consequences and high likelihoods. Minimal risks, in green, arise from unlikely or rare events with moderate or low severity. Moderate risks occupy the yellow band across the middle of the table. They include both rare events with very high severity, and likely events with minimal consequences.

Figure 3 shows five qualitative categories each for likelihood and consequence. Both parameters can be quantified, however, and should be wherever possible; for example, likelihood is the probability of occurrence of a hazard in a population of devices. However, the values that will be associated with a particular qualitative category—for example, what probability range is to be considered "likely"—will depend on the services under consideration. Such semantic difficulties can be avoided by using a quantitative scale and omitting qualitative categories.

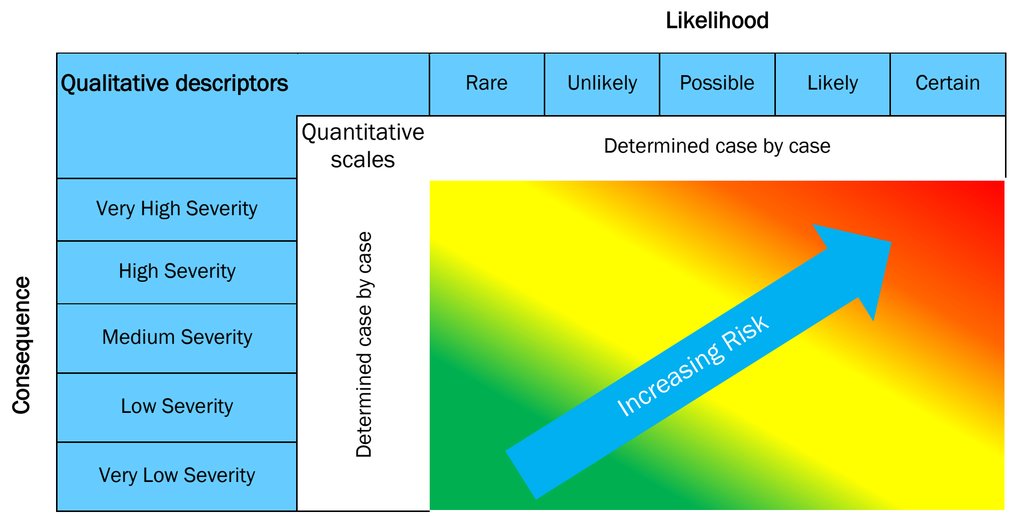


Figure 3. A generic risk chart

Risks to the operation of a service can be plotted on the chart. The location of hazards will be a function of respective service characteristics and the operating rules that are chosen, and will be matter of judgment if qualitative scales are used. For example, a working group of the National Advisory Board on Space-based Positioning Navigation & Timing plotted the risks it assessed to the GPS spectrum environment on a risk chart, excerpted in Figure 4 (Ciganer and Hatch, 2014).

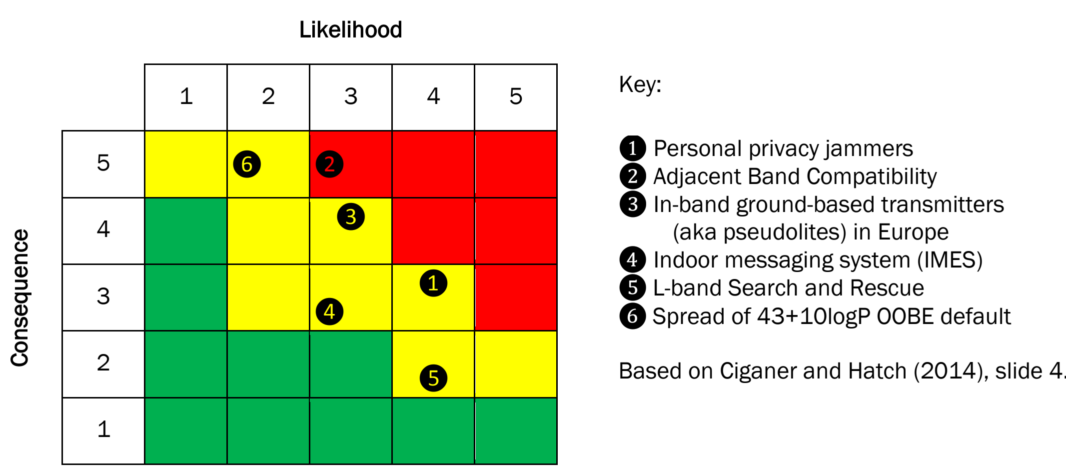
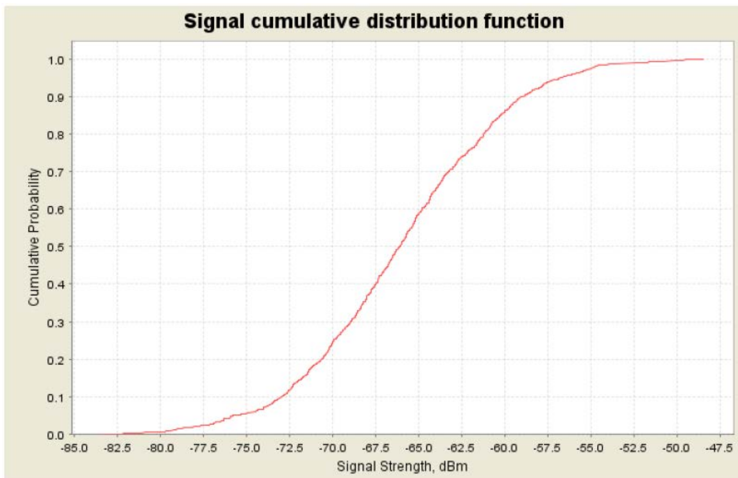


Figure 4. Perceived spectrum risks to GPS

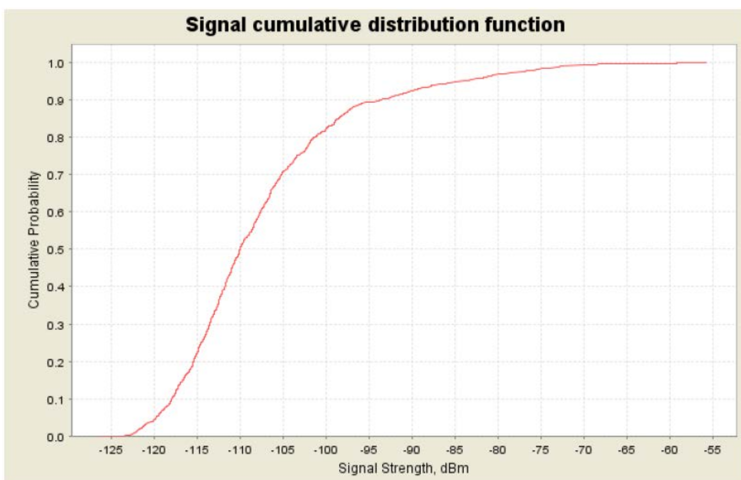
Ciganer and Hatch's assessment is qualitative: likelihood and consequence are given on a five-point scale. While such an approach deepens understanding of the nature and relative risk of hazards, quantification would provide yet further depth.

Quantification requires the numerical analysis of interference. Most factors that determine the likelihood and severity of interference will take a range of values (cf. Figure 2 for rain attenuation) so that the derived interference parameters will follow probability distributions; see e.g. Figure 5 for the wanted and unwanted power at a digital TV receiver as calculated by Aegis (2007) for Ofcom.

Wanted Power CDF at DTT Rx (Mean -66.1 dBm)



Interference Power CDF at DTT Rx (Mean -107.5 dBm)



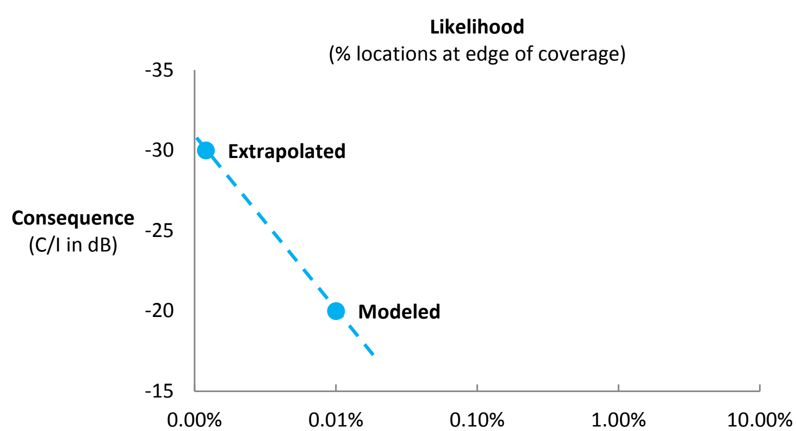
Source: Aegis (2007), Figures 10 & 11.

Figure 5. Cumulative distribution functions for wanted and interference power at a digital TV receiver

Wherever possible, probability distributions should be calculated and then combined to yield a probability distribution for the consequence metric. If it is not possible to use probability distributions and a few discrete values of parameters are used instead, it is desirable to estimate the likelihood that those values will be observed.

It is beyond this paper's scope to do a quantitative risk assessment for a particular case; an example taken from work done for other purposes will have to suffice. By combining the cumulative distribution functions for wanted and unwanted power (digital terrestrial TV signal and WiMAX handset transmission, respectively; see Figure 5) at a TV receiver at the edge of TV coverage, Aegis calculated that the desired/undesired ratio C/I is less than -20 dB for less than 0.01% of TV receiver locations. The minimum required protection ratio is -30 dB where there is no guard band, i.e. the aggregate interference power could be as high as 30 dB above the wanted power; in this case, it is higher than 20 dB for less than 0.01% of TV receiver locations (Aegis, 2007, section 2.3.3). The results are plotted on a risk chart in Figure 6, with the -30 dB value labeled as an extrapolation.

It should be underlined that rough estimates of severity and likelihood—even just orders of magnitude—will often be sufficient. For example, the Nuclear Regulatory Commission uses orders of magnitude (10^{-4}, 10^{-5}, 10^{-6}, 10^{-7}) for both baseline values and value changes of its key risk metrics—core damage frequency and large early release frequency—in its acceptance guidelines for changes in the licensing basis for nuclear power stations (NRC, 2011, section 2.4).



Source: Aegis (2007), section 2.3.3

Figure 6. Risk of interference from WiMAX handsets into TV receivers at edge of coverage.

C. Use in Risk-Informed Regulation

Regulatory decisions can be informed by plotting hazards on a risk chart.

- When making rules, one might plot the likelihood-consequence curves for different potential choices of operating parameters, e.g. transmit power ceiling or exclusion zone radius. This would generate a family of curves, one for each potential rule set, that would illustrate the risk sensitivity to various levels of operating parameters; see Figure 7 (a).
- Similarly, one could plot risk curves for various harm thresholds, using e.g. I/N values of -3, -6, and -14 dB to measure severity, and the probability of those values occurring.
- For a given choice of operating parameters and harm thresholds, one could plot the likelihood-consequence risk curves for different interference modes, e.g. OOBE, adjacent band blocking, adjacent channel interference, intermodulation, etc.; see Figure 7 (b). This would help prioritize which failure modes to focus on when choosing operating parameters.

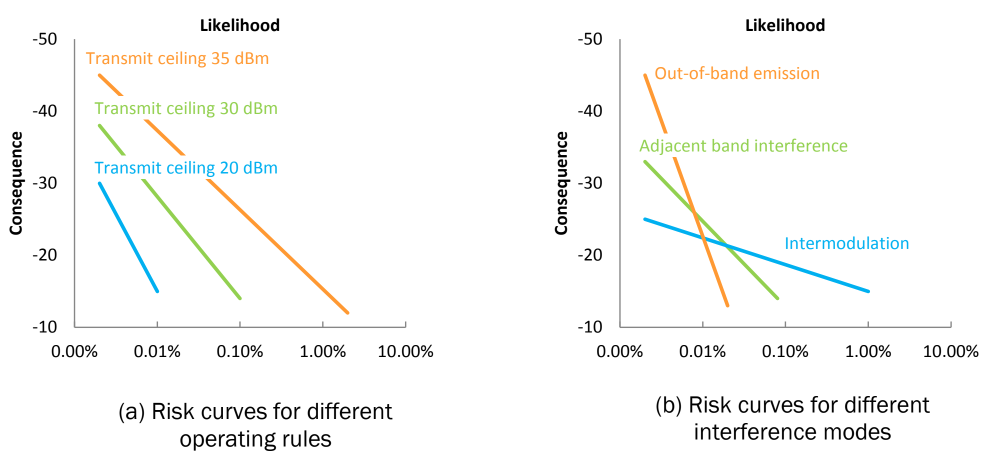


Figure 7. Families of risk curves (for illustration only—not based on data)

It should be emphasized that this approach is risk-informed and not risk-based. While technical analysis is an important input into the deliberation process, it is by no means the only factor that influences the final decision. Other considerations include the public interest, the uncertainty associated with the technical analysis, the resources and capabilities of the agency, and legal requirements.

4. Advantages of Quantitative Risk Assessment

Quantitative risk assessment is a structured way to consider and compare many failure scenarios. It can enhance the completeness of analysis and increase the chances that unexpected harmful interference mechanisms will be identified before rulemaking is complete.

It provides a more complete analysis of risk than using a single-scenario "worst case" analysis: for example, it allows the joint consideration of both pervasive, low impact interference hazards such an elevation of the noise floor that causes small but ubiquitous degradation in service quality as well as rare, catastrophic "worst case" harms.

It provides a way for comparing interference scenarios—a common currency, if you will—through the use of a single consequence metric for multiple hazard types. Quantification also creates a better picture of what the community of experts knows or does not know, highlighting areas where the record is inadequate.

Most importantly, it provides objective and actionable information to Commissioners weighing the benefits of a new service against its adverse technical impact on incumbents. While in the final analysis this is a matter of judgment, not calculation, decision makers still need understandable, comprehensive and fact-based information about the technical impact of a new service on incumbents, not just whether "harmful interference" will occur or not.[2]

5. Recommended FCC Action

The Nuclear Regulatory Commission ("NRC") pioneered quantitative risk assessment in the U.S.[3] At least two lessons can be taken from its experience. The first is that quantitative risk assessment can be applied successfully in an industry where safety-of-life is paramount. The second is that changing an industry's culture takes time, even though some constraints on the NRC—like the need to calculate very complex nuclear reactor fault trees with the limited computing power of the 80s and 90s—do not apply to the FCC's work today. It will take time for the spectrum community to become comfortable with this approach, regardless of the tools available.

[2] Economic impacts on incumbents, new entrants and the public also have to be considered but are outside the scope of this work.

[3] It first used probabilistic risk analysis in its 1975 *Reactor Safety Study*, and by 1995 the *PRA Policy Statement* had formalized the NRC's commitment to risk-informed regulation. In 2007 the *Risk-Informed Performance-Based Plan* was adopted as an "integrated master plan for initiatives designed to help the agency achieve the Commission's goal of a holistic, risk-informed and performance-based regulatory structure." See Littman & De Vries (2014).

The implication for the FCC is that it need not, and should not, start with a major overhaul of its regulatory approach; it's fine to begin with baby steps. However, given the value of quantitative risk assessment in maximizing the value of spectrum use, it is important that the Commission not delay. In other words: *Start Small but Start Soon*.

The first step is to get the spectrum community thinking about risk-informed interference analysis. Work in the TAC, the Commerce Spectrum Management Advisory Committee ("CSMAC") and other advisory groups can get the ball rolling. The FCC can develop know-how in the agency and the wider community by instituting an annual guest lecture and/or a lecture series on modern risk management that draws on luminaries who have used this approach in other agencies like the NRC, FAA and EPA, as well as practitioners in other industries. Since a solid technical basis will assist staff in performing and assessing risk studies, it would be also helpful to add courses on statistics and risk-management to the FCC University curriculum.

Next, the FCC can set a good example, and contribute to the development of know-how, by using quantitative risk assessment in its own analyses and publishing the results. Since this approach complements existing techniques, it can easily be added to the regulatory decision making process. For example:

- The Commission could begin to quantify likelihoods and consequences rather than merely using probabilistic language without quantification as it customarily does, e.g. as when it stated in AWS Service Rules R&O that "rules should be set to ensure that the probability of interference is reasonably low" without actually evaluating the probability (FCC 12-151 at ¶ 85).
- It could request disclosure and analysis of both the likelihood and consequence of harmful interference hazards in Notices of Inquiry, Notices of Proposed Rulemaking and other invitations for input.
- It could adopt as common practice a technique used in the NorthPoint case: assessing interference risk against a baseline of current impairments (MITRE, 2001; FCC 02-116; FCC 03-97).

More generally, when framing risk probabilistically and explaining its judgments, the FCC should document both relative and absolute changes in interference impacts, as well as giving the probability of being unaffected by new rules.

The Commission can pilot the use of quantitative risk assessment in proceedings with limited scope. Applications for site-specific waivers to service rules appear to be a good candidate (Cox, 2014). Quantitative risk assessment should not substantially increase the current waiver review period, which is typically six months and often longer. It should not substantially alter the waiver review process, since waivers are regularly opposed and already receive in-depth review from the FCC. There are also enough site-specific waiver requests—about half a dozen a year—that the FCC will have a good population from which to select pilot projects. Site-specific waivers (about a third of the total) reduce the number of variables the FCC would have to consider and limit the geographic impact of risk-informed decisions.

Finally, increased up-front certainty about acceptable and unacceptable interference risks, ideally as a general matter or if necessary on a case-by-case basis, would encourage innovation and investment. The Commission could use risk charts to delineate likelihood-consequence boundaries above which interference risk was deemed to be excessive a priori (the red zone in a risk chart) or below which it would not be a concern (the green zone). The hard work of regulatory judgment falls between them in the yellow zone, but limiting the area of dispute would encourage parties to find consensus.

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