ASSESSING LOW-PROBABILITY, HIGH-IMPACT EVENTS

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Introduction

The purpose of this report is to help stakeholders design and interpret cases that test the economic performance of a transmission line under alternative conditions. The need to fully understand all the potential economic impacts of a transmission project has reached the point where evaluation of a single base case often does not provide sufficient information to make an informed decision. However, sometimes studies of multiple cases produce so much information that it becomes overwhelming to organize and make sense of all the data. Decision makers often aren't sure how much weight to assign individual 'reasonable' or 'outlier' cases, and are not confident that all relevant cases were studied.

A good study design produces cases based on sound logic and produce standardized results that allow meaningful comparisons with the alternatives studied. The purpose of this paper is to provide an understandable summary regarding:

- A general methodology for developing cases.
- The purpose of studying different kinds of cases.
- An illustration of the methodology using the recent California Independent System Operator (CA ISO) case study of the Palo Verde-Devers No. 2 (PVD2) Transmission Project.

A draft report and presentation of this report was provided at the California Energy Commission (Energy Commission) July 28, 2005, "Integrated Energy Policy Report Committee Hearing on Strategic Transmission Planning Issues and Transmission Staff Report."[1] Parties were invited to file comments regarding this and other presentations provided on July 28, 2005, by August 4, 2005.[2]

Proposed General Methodology

Stakeholders and decision makers need a basis for evaluating whether a transmission benefit study has been constructed in a useful manner. In this section, we propose a general framework that can be used for conducting benefits assessments. This framework is designed to be basic enough that it can be readily used and understood by the wide range of parties involved in the decision to build or improve a transmission line: utility resource or transmission planning departments, regulatory bodies, market operators, and project proponents and interested interveners.

For the most part, the evaluation of a proposed transmission addition includes properly-selected sensitivity cases. However, it is important to recognize that, in some situations, sensitivity cases may not be necessary. For example, if the computed present value (PV) of benefits of the transmission expansion is

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[1] See website: [http://www.energy.ca.gov/2005_energypolicy/documents/index.html#072805].
[2] See website: [http://www.energy.ca.gov/2005_energypolicy/notices/2005-07-28_hearing_notice.html].

significantly greater than the corresponding PV of revenue requirements (or cost to the consumer), then further evaluation may not be critical because additional analyses will be highly unlikely to change the positive benefit/cost relationship and the resulting decision. In a similar manner, if the PV of benefits is considerably less than the PV of revenue requirements, additional sensitivity cases may not be necessary since a positive result would be unlikely.

For most transmission evaluations where changes in the assumed conditions can result in differing benefits levels, sensitivity cases are important. The proposed general methodology for the selection and development of low-probability, high-impact cases consists of the following tasks:

A. Establish stakeholder process
B. Develop reference case
C. Select uncertain variables
D. Develop variable probability distributions
E. Select sensitivity cases
F. Determine joint probability
G. Perform simulations and summarize results

Task A - Establish Stakeholder Process

A properly designed and executed stakeholder process can be invaluable in ensuring that the project is reviewed in a comprehensive manner considering all alternative perspectives and priorities. An effective and efficient stakeholder process should result in an agreement about which types of sensitivity cases to include in the evaluation before beginning the study. To accomplish this, stakeholders must consider the purposes of the line, the kinds of uncertainties which might affect the value of the line, and the uncertainties which are of most concern to them. Usually, because of time and data availability constraints, only a subset of potential alternatives can be studied. So it is vital that parties agree on which studies are most valuable. Otherwise, the proceeding may be delayed at a later point by concerns that the appropriate set of cases was not studied.

Task B - Develop Reference Case

Before the uncertain variables are selected, it is important to develop a reference case using the base assumptions for all parameters (or expected conditions). Using this simulation and performing preliminary one-parameter sensitivity experiments can derive initial conclusions about the following critical information:

- The time required to correctly model each case including assumption development, execution, review, and iteration, as appropriate.
- The variables where changes from expected conditions have a significant impact on the results.

Task C - Select Uncertain Variables

In this task, the project evaluator identifies variables with a high degree of uncertainty surrounding their expected condition and a significant impact on the results. These variables fall into one of the following three classes:

- Quantifiable events with known or predictable probabilities (e.g., hydro, load, fuel price).
- Quantifiable events with unknown probabilities (e.g., events with little available historical data to make predictions).
- Difficult to quantify events with unknown probabilities (e.g., new market paradigm).

The sensitivity studies should include the first two classes of variables. However, only those variables that can be quantified with known or predictable probabilities should be used in the expected value and distribution of benefits calculations.

Task D - Develop Variable Probability Distributions

The next step, once uncertain variables are selected and their values for the base-case forecast estimated, is to develop a probability distribution. This distribution provides a plausible range of future values for each variable and its relative probability of occurrence.

There are several well-documented and accepted approaches for developing probability distributions. They include using historical observations and observed forecast errors. Since the potential benefits of transmission projects often depend upon the occurrence of extreme events, a reasonable approach is to compile a base case and select a range bounded by a relatively large confidence interval (e.g., a 90 percent confidence interval). The base case uses the expected (or forecasted) value for each variable discussed in Task A. The sensitivity cases can consider three levels for each uncertain variable:

Very High	Upper bound of the 90% confidence interval.
Base	Expected value of the variable.
Very Low	Lower bound of the 90% confidence interval.

Additional variable levels such as high and low need not be included since their results are likely to be less informative or valuable than the extreme cases.

Task E - Select Sensitivity Cases

Using the concept of "Importance Sampling" (explained in more detail later in the report), the number of required simulations can be reduced to a manageable level. If four variables with three specified conditions are selected, the total universe of cases is 81. Using the three categories of cases outlined above, the number of cases can be reduced to the following:

- Most likely – 1
- Bookend – 2 to 16
- Most useful for analytical comparisons – 8

The most likely case would use the base case assumptions for all four variables. The bookend cases would use the very-high or very-low values for all four variables. The total combinations of bookend cases is 16 cases (i.e., 2^4). The analytical comparison cases could use one variable at either its very-high or very-low value, with the other three variables set at a base or reference level. These cases are enumerated in Appendix A.

Task F - Determine Joint Probability

In order to ensure that all possible conditions have been considered, the joint probabilities should sum to one and the total probability of each variable should sum to one (e.g., all low hydro cases should sum to 15 percent, base equal to 70 percent, and high equal to 15 percent). To accomplish this, we recommend the use of a mathematical approach such as the Maximum Log-Likelihood linear program.[3] These mathematical techniques assign weights to cases so that a variable's low outcome has the same probability as the high outcome.[4]

Task G - Perform Simulation and Summarize Results

In this task, actual market simulations are performed. Each case is modeled twice – with and without the proposed transmission addition in the resource mix. Generally, the societal results are reviewed first to ensure that the direction of the benefits (increase or decrease) are either intuitive or can be explained. Once the simulations are completed, the results are used to compute the benefits from the desired perspectives, such as California ratepayers. The expected value and benefit distribution can be derived for each of the desired perspectives. Benefits can be interpolated for interim years, or extrapolated for remaining years using the expertise and judgment of the analyst.

Purpose of Sensitivity Cases

The value of a transmission expansion is dependent upon a number of uncertain variables. These variables may include load growth, fuel prices, hydro conditions, the amount and location of new generation, the ability to exercise market power, and others. Some of these uncertainties can be easily quantified, and others cannot.

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[3] In statistics, the likelihood is defined as the probability of specific input parameter given the observed results. For example, assume a coin is tossed 100 times and we observe 56 heads and 44 tails. Given those observed results, we can derive that the Maximum Likelihood Estimate (MLE) is a probability of 56 percent for heads. In a similar way, we are deriving the maximum likelihood of input parameters such as hydro. Also, the reason for using the natural log of the likelihoods instead of the likelihoods themselves is computational rather than theoretical. With log-likelihoods, probabilities are simply added together instead of multiplied to reduce rounding errors and improve accuracy (Maximum Log-Likelihood Primer).

[4] "Responses to Comments Received by the Market Surveillance Committee (MSC) On Team Analysis for PVD2", CA ISO, February 10, 2005, p. 2.

There are several fundamental reasons why uncertainty needs to be considered with respect to transmission expansion benefits. The two primary reasons are:

- Expected Value
- Distribution of Benefits

Expected Value

The uncertainty of future conditions may have a considerable impact on the value of the transmission line (e.g., higher-than-expected gas prices might increase the value of the transmission line significantly). The impact of this uncertainty on the expected value of the benefits may not be predictable without specifically analyzing the base, high, and low cases.

For example, the value of a proposed transmission addition, assuming average future conditions, may be $40 million. Under a low-gas price case, the benefit might be $30 million. Under a high-gas price case, the benefits may be $60 million. Assuming each of the three cases had an equal probability of occurrence, the expected value of the proposed addition would be approximately $43 million. As this simplified example illustrates, the reference (or base) case benefits (i.e., based on average conditions) can be significantly different from the "expected" value of benefits (i.e., derived from multiple sensitivity cases, multiplied by their respective probability of occurrence).

Evaluating a transmission project based on average future conditions might underestimate or overestimate the true value of the expansion. Therefore, it is important to derive an "expected" value of benefits based on multiple cases, rather than just using the "average" benefits.[5]

The difference between the average and the expected value of benefits may be insignificant or it may be considerable. In the Path 26 study developed by the CA ISO, the difference in annual benefits in 2013 from the CA ISO participant perspective was significant. This is illustrated in Figure 1.[6]

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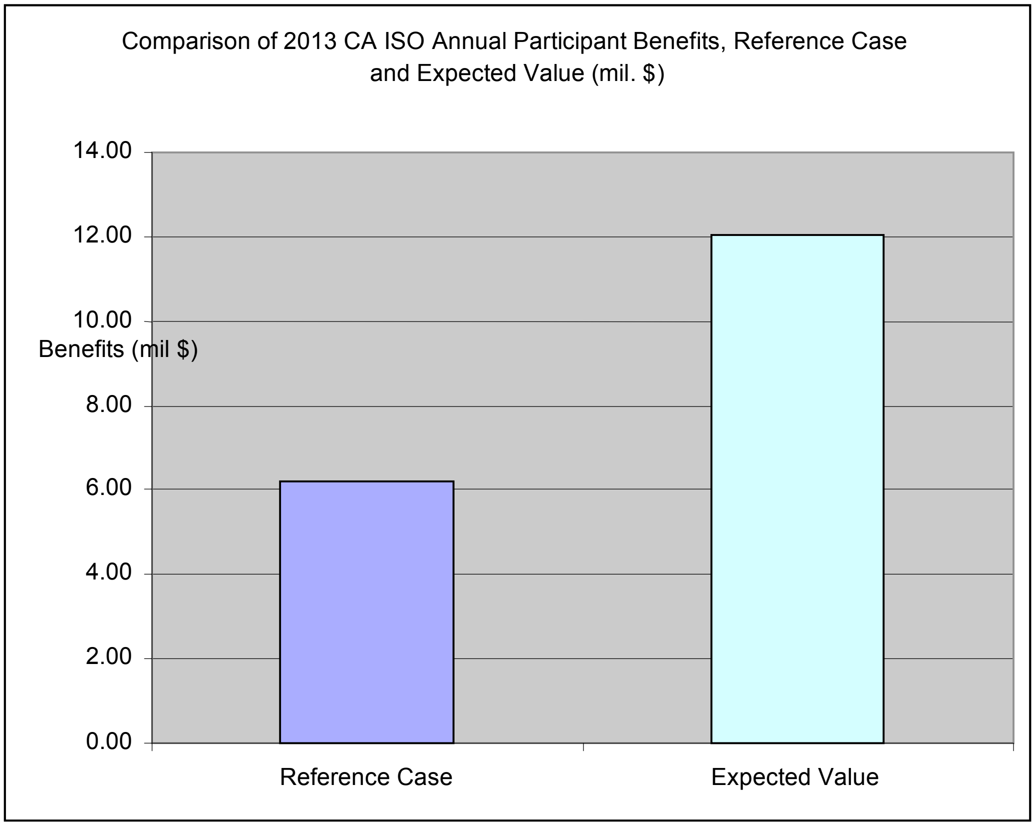
[5] Average benefits are sufficient if the reference case is overwhelmingly economic or uneconomic. If the average benefits are not clearly economic or uneconomic, sensitivity cases are required to more accurately understand the expected value and distribution of benefits.

[6] "Supplement to the Transmission Economic Assessment Methodology Report" CA ISO, (CA ISO TEAM Supplement), July 28, 2004, pp. 5-3 and 5-5.

Figure 1
Comparison of 2013 CA ISO Annual Participant Benefits, Reference Case and Expected Value (mil. $)



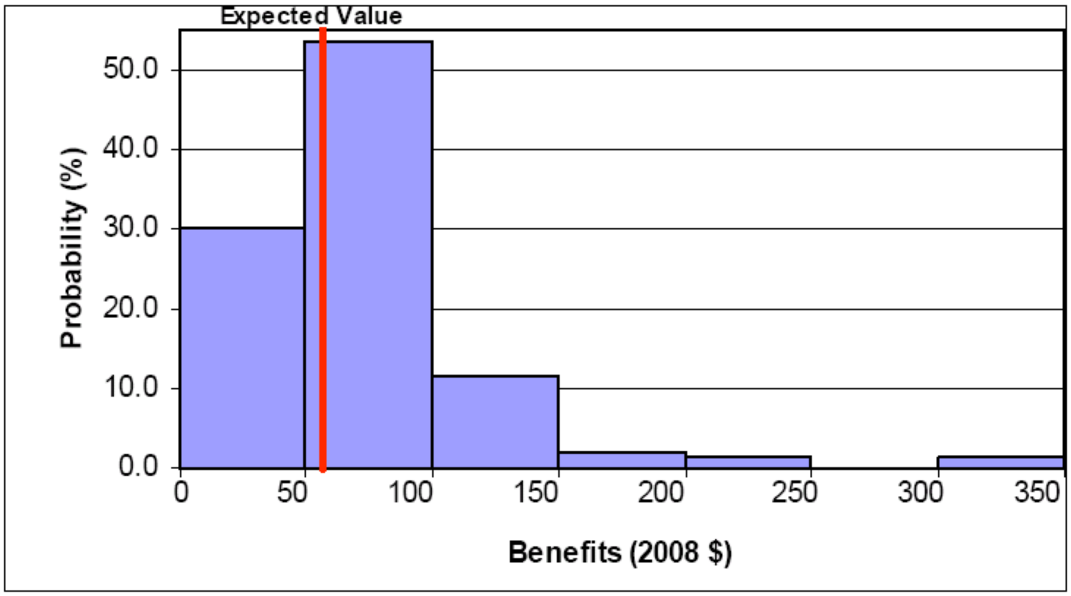
The transmission benefits derived from a single reference or base case, compared with the expected value of benefits computed from numerous sensitivity studies, can be substantially different, as shown in the example in Figure 1, above. Hence, it is important to calculate and use the expected value of benefits when comparing resource alternatives.

The comparison between the reference case and the expected value of benefits is generally not as significant as the difference shown in Figure 1. The two values can be much closer, or the order can be reversed with the value of the reference case exceeding the expected value. All of these situations occurred in the CA ISO Path 26 study (i.e., for different years and perspectives).

Distribution of Benefits

As discussed in the previous section, the expected benefit of the proposed transmission addition is derived from multiple sensitivity cases and their respective probabilities. This same information can be used to summarize the distribution of benefits. A distribution of benefits is a valuable decision-making tool since the distribution summarizes the downside risk and upside-benefit potential of a resource alternative. An example of a probability benefit distribution for the proposed PVD2 expansion is shown in Figure 2, below.

Figure 2
Probability Distribution of Energy Benefits, 2013, CA ISO Ratepayer Perspective



The probability distribution of benefits above provides a snapshot of the magnitude of risk associated with a given resource option or portfolio for a single year. This distribution allows the risk of a given investment to be quantified and used in the resource selection process.

In Figure 2, the blue vertical columns represent the probability that the energy benefits of the proposed PVD2 upgrade will fall into the specified benefit range or bin. For example, there is a 30 percent probability that the annual energy benefits are between $0 and $50 million[7]. The red vertical line represents the expected $56 million value of benefits in the year 2013, from the CA ISO ratepayer perspective.

Assume for the purposes of this example only that the annual capital and fixed operating costs of the proposed upgrade are $50 million. If the expected value of benefits is $56 million, the benefits outweigh the costs and the project appears to be

[7] The benefits of the proposed PVD2 are considered to include energy, operational, loss, capacity, and emission benefits. The energy benefits shown in Figure 2 are considered only part of the overall benefits. See CA ISO PVD2 Report, p. 31.

economically justifiable (for that year and perspective). Although this conclusion is valid, the distribution of benefits provides much more information, such as:

- There is a 70 percent probability that the annual benefits will be equal to or greater than the annual costs.
- There is zero probability that the project will have non-positive benefits over a year (i.e., that the project will actually increase system costs).
- There is a 5 percent probability that the project will provide annual benefits of between $150 and $350 million, providing some insurance value against extreme events in the unlikely event they occur.

If another alternative had the same expected value of $56 million but the distribution showed limited upside potential and the possibility of negative benefits, on the basis of the respective risk distributions alone, the first alternative might be selected. Therefore, the benefit distribution is important in helping the decision maker(s) better understand the risks of one alternative (i.e., probabilities to the left of the expected value in the graph) and the upside benefit potential (i.e., probabilities to the right of the expected value) relative to another resource alternative with different risk characteristics.

The probability distribution will also help indicate whether extreme events can be expected to have a significant impact on the expected value, and to what extent these cases should be developed and modeled. As a general observation, the expected value of transmission upgrades is expected to be significantly impacted by these extreme events (i.e., to the extent that the extreme events are able to be modeled and a probability assigned to them).

Dr. Frank Wolak, chairman of the CA ISO Market Surveillance Committee and a professor of economics at Stanford University, states that "transmission upgrades are particularly valuable during extreme conditions." As an example, Dr. Wolak suggests that if a significant inter-connection existed between the eastern United States and the Western Electricity Coordinating Council (WECC), prices in the WECC would not have risen to the levels that existed during the period of May 2000 to June 2001. Dr. Wolak has estimated that the savings that such an interconnection would have provided during this time period would have been "on the order of $30 billion."[8]

Therefore, the consideration of extreme events can be a critical factor in deriving both the expected value and the distribution of benefits.

[8] "Valuing Transmission Investment in a Wholesale Market Regime," Dr. Frank Wolak, Department of Economics, Stanford University, Chairman, Market Surveillance Committee, February 3, 2004, pp. 13-29. See website: [http://www2.caiso.com/docs/2003/03/18/2003031815303519270.html].

Case Study -- Selection of Sensitivity Cases for PVD2

The previous section concluded that the inclusion of low-probability, high impact events (also referred to as "extreme events" in this report) generally has a significant impact on both the expected value and the probability distribution of benefits. The purpose of this section of the report is to provide a case study for the non-technical reader illustrating the methodology used to select and evaluate low-probability, high-impact events.

The CA ISO recently completed an evaluation of the economic viability of the proposed 1,200 MW PVD2 Project. This study analyzed the impact of uncertainty by developing numerous alternative cases. In theory, hundreds or thousands of cases could have been developed for each transmission line in order to evaluate the universe of possible future conditions and accurately derive expected values and benefit distributions from a statistical perspective. Ultimately the sensitivity cases selected were developed utilizing a stakeholder working group to identify both key concerns and high risk scenarios of potential interest to decision makers.

In the PVD2 study, the four key variables that were expected to have a significant impact on the economic benefits were:

- Load growth throughout WECC
- Hydro conditions
- Natural gas price
- Generator market power

For each of these four key variables, three different cases were developed that corresponded with very low, average, and very high conditions, based on a 90 percent confidence interval.[9] There were 81 possible sensitivity case combinations of these four variables (3 x 3 x 3 x 3). Given the complexity of modeling each case for 8760 hours, for two separate years (2008 and 2013), and using a detailed WECC transmission network, it was not possible to model each of the 81 cases separately.[10]

The CA ISO used a scientific sampling method called "importance sampling" to select a smaller but still representative number of possible cases. Importance sampling was used to choose scenarios that represented:

- Most likely conditions
- Extreme "bookend" conditions
- In between conditions useful for analytic comparison

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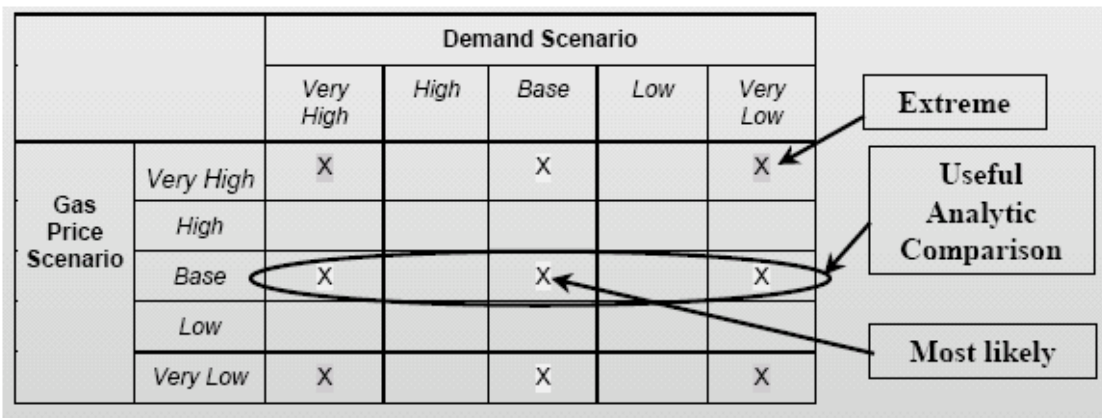
[9] CA ISO Board Report, p. 8.

[10] The WECC representation used in the PVD2 study included 17,500 transmission lines, 13,400 nodes, and 800 generation plants.

Dr. Benjamin Hobbs, a member of the CA ISO Market Surveillance Committee (MSC) and a professor at Johns Hopkins University, used the following table to illustrate how to choose joint events of load and gas price levels using importance sampling. In this example, the most likely case is (B, B). The bookend cases are (VH, VH), (VH, VL), (VL, VL), (VL, VH). The most useful analytic comparisons are (B, VH), (B, VL), (VH, B), and (VL, B). In Dr. Hobbs' example, after applying importance sampling, there are nine cases based on three levels for each variable instead of the original 25 cases.[11]

Table 1
Application of Importance Sampling



		Demand Scenario				
		Very High	*High*	*Base*	*Low*	*Very Low*
Gas Price Scenario	*Very High*	X		X		X
	High					
	Base	X		X		X
	Low					
	Very Low	X		X		X

In the PVD2 study, importance sampling was used to subjectively select 25 sensitivity cases from the 81 possible cases. The 25 selected cases were designed to meet the three criteria summarized above: (a) most likely; (b) extreme bookend; and (c) those useful for analytic comparison.

After the number of potential cases was significantly reduced, probabilities were assigned to each of the 25 cases using a mathematical approach referred to as "Maximum Log-Likelihood."[12] Of the 25 cases that were assigned probabilities with Maximum Log-Likelihood, approximately 8 of those cases were assigned probabilities of zero. Thus, these 8 cases were dropped, and the remaining 17 cases were modeled. These 17 cases and their relative joint probabilities are summarized in the following table.[13]

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[11] "CA ISO Proposed Transmission Expansion Evaluation Methodology – Sensitivity and Risk Analyses: Why and How," Benjamin Hobbs, CA ISO Market Surveillance Committee, February 3, 2004. See website: [http://www1.caiso.com/docs/2003/03/18/2003031815303519270.html].
[12] "Economic Evaluation of Palo Verde Devers Line No. 2 (PVD2), Technical and Other Appendices," CA ISO, (CA ISO PVD2 Technical Appendices), Appendix A, p. 6.
[13] For an introductory discussion of the Maximum Log-Likelihood algorithm, refer to website: [http://statgen.iop.kcl.ac.uk/bgim/mle/sslike_4.html], section 3 (Maximum Log-Likelihood Primer).

Table 2
2008 Market-Based Cases with a Joint Probability

PVD2 Case Summary

A	B	C	D	E	F
Case no.	**Load**	**Gas Price**	**Hydro**	**Market Pricing**	**Joint Probability**
17	B	B	B	M	11.0%
18	B	B	B	H	5.0%
19	B	B	D	M	9.9%
20	B	B	W	M	13.1%
21	B	H	B	M	2.3%
22	B	H	B	H	1.8%
23	H	B	B	H	3.3%
24	H	H	D	M	1.8%
25	B	H	D	H	1.8%
26	B	B	B	L	15.0%
27	L	B	B	M	12.7%
28	B	L	B	M	10.1%
29	H	H	B	H	1.6%
30	H	L	B	M	4.9%
31	L	H	B	M	2.3%
32	H	H	D	H	1.5%
33	H	H	W	M	1.9%
High	15.0%	15.0%	15.0%	15.0%	
Base	70.0%	70.0%	70.0%	70.0%	
Low	15.0%	15.0%	15.0%	15.0%	
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

B = Baseline; H = High; L = Low; D = Dry; W = Wet; M = Moderate

One frequent stakeholder question was if low-probability, high-impact events were over-represented. For example, in Column C there are eight cases of "high" gas prices and only two cases of "low" gas prices. As a result, it appeared to some stakeholders that the high gas case was over represented.

However, if one sums the probabilities of all high gas cases and then compares it with the sum of probabilities of all "low" gas price cases, the two probabilities both equal 15 percent. The result is the same for each of the four variables. The sum of probabilities of the high and low cases is 15 percent. The probability of the base case is 70 percent.

Developing additional low cases would not have been particularly interesting since they would represent cases that were primarily in the lower benefit ranges. For example, more low hydro cases would fall in the benefits range of $0 to $50 million. Additional low hydro cases would better define the shape of the benefit distribution curve below $50 million, but these results would be unlikely to change any decision to proceed or not proceed with development of the transmission expansion. On the other hand, understanding the low-probability, high-impact (or benefit) cases was important because of their potential impact on the expected value and the insight they provided about the upside benefits under extreme conditions.

A second question also frequently asked by stakeholders was why the joint probability of any individual case was not equal to the product of the marginal probabilities. For example, Case #32 in Table 2 is composed of four high events (high load, high gas price, high market price, and dry hydro). The joint probability of those four outcomes is about 0.05 percent, almost zero, if one uses the marginal probability of 15 percent (i.e. 15% x 15% x 15% x 15%). Yet the probability shown in Table 2 is 1.5 percent, much higher than the calculated joint probability of 0.05 percent.

If we were to model the full universe of potential cases (i.e. 81 cases), then the joint probability for each case would be the product of the marginal probabilities for each of the four variables. However, since only 25 cases were selected for modeling using importance sampling, the probabilities of those cases must sum to one and represent the universe of cases. The mathematical approach used to assign probabilities to the 25 cases is called the Maximum Log-Likelihood linear program.[14] This technique is discussed further in the following section.

There are three types of sensitivity cases that the CA ISO used in its evaluation of PVD2. These categories were:

- Cost-based cases
- Market-based cases with probabilities
- Contingency cases

The cost-based cases were used to understand the fundamental reasons behind the benefits of the proposed transmission expansion without the additional complexity of trying to model market price responses. These cases helped identify modeling issues that needed to be resolved before the market-based cases were developed. The cost-based cases were not used in the expected value or distribution of benefits calculations.

The 17 market-based cases summarized in Table 2 represent all information used to determine the expected values and benefits distribution. The majority of the CA ISO analytical effort was spent in developing these cases, which then formed the backbone of the economic analysis.

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[14] "CAISO PVD2 Technical Appendices", Appendix A, p. 6 of 68.

The third category of cases was extreme events that could not be assigned a probability. These cases were important because they provided an understanding of the value of the transmission line and the range of potential benefits. Since the contingency cases did not have a probability of occurrence they were not included in the expected value or benefit distribution calculations.

In addition to the 17 market-based cases with joint probabilities summarized in Table 2, 8 contingency cases were developed to represent extreme cases in which it was difficult to assign probabilities. The cases were picked by examining what major changes to generation or transmission would affect the value of a new transmission line between Arizona and southern California. These contingency cases included:

- Year-long unavailability of key generation or transmission facilities, including Palo Verde Units 1 and 2, Mountain View, San Onofre, and the Pacific DC Intertie.
- Increased capacity made available by the inclusion of Mohave Generating Station in Arizona.
- Ten percent de-rating of the bulk transmission lines going north and southwest (California-Oregon Intertie and East-of-River interface)
- Southern California Edison early retirement of about 1000 MW of gas-fired, in-basin units.[15]

[15] “CAISO PVD2 Technical Appendices”, Appendix A, p. 7/68.

Appendix A: Possible Cases After Using Importance Sampling

Importance Sampling Criteria	Case No.	Case Descriptions
Most Likely	1	B,B,B,B
Bookend	2	H,H,H,H
	3	H,H,H,L
	4	H,H,L,H
	5	H,H,L,L
	6	H,L,H,H
	7	H,L,L,H
	8	H,L,L,H
	9	H,L,L,L
	10	L,H,H,H
	11	L,H,H,L
	12	L,H,L,H
	13	L,H,L,L
	14	L,L,H,H
	15	L,L,L,H
	16	L,L,L,H
	17	L,L,L,L
Most Useful	18	H,B,B,B
	19	L,B,B,B
	20	B,H,B,B
	21	B,L,B,B
	22	B,B,H,B
	23	B,B,L,B
	24	B,B,B,H
	25	B,B,B,L