The California ISO Transmission Economic Assessment Methodology (TEAM): Principles and Application to Path 26

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Abstract—**In response to the novel requirements that restructured power markets place upon transmission planning, a method for assessing the economic benefits of transmission upgrades has been adopted by the California Independent System Operator (CAISO). Economic effects considered include reductions in the cost of constructing and operating power plants along with changes in market prices. The methodology accounts for how transmission upgrades mitigate market power by increasing the size of a supplier's geographic market. The methodology has five key principles: consideration of multiple perspectives (consumers, generators, transmission operators, and society at large); full network representation using a linearized DC loadflow; market-based pricing, accounting for strategic behavior by generators; modeling of uncertainty, including the value of transmission as insurance against extreme events; and recognition of how supply, demand-side, and transmission resources can substitute for each other. An application to a possible expansion of Path 26 in California is summarized. The application shows how a substantial portion of the benefits of transmission reinforcements can derive from their mitigation of market power.**

Index Terms—**Transmission System Planning, Economics, Competition, Market Power, Uncertainty, Linearized DC Model**

I. INTRODUCTION

THE need for new transmission planning processes that respond to the new demands of a restructured power industry is widely acknowledged [1-9]. Unlike the previous vertically integrated regime in which a single regulated utility was responsible for serving its load, the restructured wholesale electric market is comprised of a variety of parties independently making decisions that affect the utilization of transmission lines. This new market structure requires a new approach to evaluate the economic benefits of transmission expansion. Specifically, the new approach must address the impact a transmission expansion would have on (a) transmission users' access to customers and generation sources, (b) incentives for new generation investment, and (c) market competition. The approach must also account for the inherent uncertainty associated with key market factors such as hydro conditions, natural gas prices, and demand growth. Integrating all of these critical modeling requirements into a comprehensive methodological approach is a challenge. The CAISO has developed a planning approach that considers these elements called the Transmission Economic Assessment Methodology (TEAM) [10].

The methodology was developed because the CAISO is responsible for evaluating the need for all potential transmission upgrades that California ratepayers may be asked to fund. This includes construction of transmission projects needed either to promote economic efficiency or to maintain system reliability. The CAISO has clear standards to use in evaluating reliability-based projects. TEAM will help the CAISO to fulfill its responsibility for identifying economic projects that promote efficient utilization of the grid.

The goal of TEAM is to streamline the evaluation process for economic projects, improve the accuracy of the evaluation, and add greater predictability to the evaluations of transmission need conducted at the various agencies. Depending on the environmental and economic attributes of a proposed transmission project and the project sponsor, a number of agencies can have planning and approval roles. In a number of previous cases, especially in determining project need, the CAISO has seen that the same project has received multiple reviews by various agencies, each seeking to carry out their individual mandates. It has been recognized that this process has led to redundancies and inefficiencies [11,12]. We believe that accepting the TEAM methodology as the standard for project evaluation by market participants, stakeholders, regulatory and oversight agencies will reduce redundant efforts and lead to faster and more widely supported decisions on key transmission investment projects.

The TEAM methodology is based upon five principles for defining quantifiable benefits. The methodology provided here represents the state-of-the-art in the area of transmission eco-

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nomics and planning in terms of its simultaneous consideration of the network, market power, uncertainties, and multiple evaluation perspectives. This modeling framework provides a template containing the basic components that any transmission study in California should address, providing standards for the minimum functionality that modeling software should have. The methodology is intended to be a tool that will provide market participants, policy-makers, and permitting authorities with the information necessary to make informed decisions when planning and constructing a transmission upgrade.

This paper describes the elements off the TEAM methodology for assessing the economic benefits of transmission expansions for wholesale market environments in the face of uncertainty. It also summarizes an application of TEAM to a proposed transmission expansion between central and southern California called Path 26.

II. FIVE PRINCIPLES

The transmission valuation methodology we propose here offers five major enhancements to traditional transmission evaluations, which we call "principles." Although specific application of these principles may vary from study-to-study, the CAISO requires that the following five requirements be considered in any economic evaluation of proposed transmission upgrades presented to the CAISO for review. The five key principles of the proposed CAISO methodology do not need to be applied in exacting detail for each study. Rather, the type of study and initial study results will dictate at what level the principles should be applied.

A. First Key Principle: Benefit Framework

Decisions on economic-driven transmission investment have suffered due to a lack of a standardized benefit-cost analysis framework. Such a framework would enable users to clearly identify the beneficiaries and expected benefits of any kind of transmission project, for both private and regulated transmission investments. Our benefit framework addresses this problem. It provides a standard for measuring transmission expansion benefits regionally and separately for consumers, producers, and transmission owners for any kind of economic-driven transmission investment.

Consumer benefits in a vertically integrated utility come from three sources – reductions in consumer costs, increases in net revenue for utility-owned generation, and the increase in utility-derived congestion revenue. In our method, we separated the total change in production costs resulting from a transmission expansion into three separate components – Consumer Surplus, Producer Surplus, and Transmission Owner (Congestion Revenue) Benefits. Positive benefits indicate an increase in a party's benefits. Negative numbers indicate a decrease.

These benefit amounts can be summed and viewed from a Western interconnection-wide societal or sub-regional perspective or California ratepayer perspective. A critical policy question is which perspective should be used to evaluate projects. The answer depends on the viewpoint of the entity the network is operated to benefit. If the network is operated to maximize benefit to ratepayers who have paid for the network, then some may consider the appropriate test to be the ratepayer perspective. Others say this may be a short-term view, which does not match the long-term nature of the transmission investment. In the long run, it may be both the health of utility-owned generation and private supply that is needed to maximize benefits to ratepayers. Advocates of this view claim that the network is operated to benefit all California market participants (or for society in general) and, therefore, the CAISO participant or Western Electricity Coordinating Council (WECC) perspective of benefits may be the relevant test.

Each perspective provides the policy makers with some important information. If the benefit-cost ratio of an upgrade passes the CAISO participant test, but fails the WECC test of economic efficiency, then it may be an indicator that the expansion will cause a large transfer of benefits from one region to another.

On the other hand, if the proposed project passes the societal test but fails the CAISO participant test, this may indicate that other project beneficiaries should help fund the project rather than just CAISO ratepayers. Policy makers should review these differing perspectives to gain useful information when making decisions [6].

An additional consideration on viewing various perspectives of the benefits of a transmission expansion is how to treat the loss of monopoly rents by generation owners when the grid is expanded. Since monopoly rents result from the exercise of market power that reduces efficiency and harms consumers, it has been argued that it is reasonable to exclude the loss of monopoly rents in the benefit calculations. (Monopoly rents are distinguished from scarcity rents that arise in competitive markets.) This is the key difference between the WECC societal test and the WECC modified societal test (based on societal benefits minus monopoly rents). Monopoly rents for California producers are also excluded from the CAISO participant test since it considers only California competitive rents.

B. Second Key Principle: Network Representation

It is important to accurately model the physical transmission flow to correctly forecast the impact of a potential transmission upgrade. Models using a contract path method may be sufficient for many types of resource studies, but that approach is insufficient when analyzing a transmission modification that will impact regional transmission flows and L MPs.

We have recently seen how critical an accurate network representation is to making a correct decision. One California utility proposed a transmission addition and justified its economic viability using a contract-path model. When the CAISO reviewed the case, it found the line to be uneconomic due to its adverse physical impact on the other parts of the transmission system. The simpler transmission model used by the utility produced inaccurate results, making the upgrade appear economic because the actual physical impact of the upgrade was incorrectly modeled.

Accurate physical transmission modeling is also important to ensure that reliability and delivery standards are achieved. Since these standards are based on physical line flows and not contract flows, a detailed network model is necessary.

There are many different analytical techniques for modeling physical transmission networks. More advanced techniques may provide more accurate information but also increase the data burden and execution time. Recognizing these tradeoffs, the CAISO identified the need to model the correct network representation provided in WECC base cases. Any production cost program that utilizes this network model should include at least the following capabilities:

- it performs either a DC or AC OPF that correctly models the physical power flows on transmission facilities for each specific hourly load and generation pattern;
- it is capable of modeling and enforcing individual facility limits, linear nomograms, and path limits;
- it can model limits that depend on variables such as area load, facility loading, or generation availability;
- it is capable of modeling only those limits of interest (typically only 500 kV and selected 230 kV system limits);
- it models phase shifters, DC lines, and other significant controllable devices;
- it can calculate LMPs;
- it can plot hourly flows on individual facilities, paths, or nomograms; and
- while not required, it is desirable for the simulations to model transmission losses.

While our methodology requires use of a network model, a simplified analysis (contract path or transportation models) can be utilized if desired to screen a large number of cases for the purpose of identifying system conditions that may result in large benefits from a transmission expansion.

C. Third Key Principle: Market Prices

Historically, resource-planning studies have typically relied on production cost simulations to evaluate the economic benefits of potential generation and transmission investments. Such an approach made sense when utilities were vertically integrated and recovered costs through regulated cost-of-service rates. But assuming marginal cost bidding in a restructured market environment where suppliers are seeking to maximize market revenues may distort benefit estimates. In a restructured electricity market, suppliers are likely to optimize their bidding strategies in response to changing system conditions or observed changes in the behavior of other market participants. Because of this, a methodology for assessing the benefits of a transmission project in a restructured market environment should include a method for modeling strategic bidding. Modeling strategic bidding is particularly important because transmission expansion can provide significant benefits to consumers by improving market competitiveness. A new transmission project can enhance competition by both increasing the total supply that can be delivered to consumers and the number of suppliers that are available to serve load. On the other hand, imperfect competition can, in theory, diminish the benefits of transmission connections, as shown in [17].

There are two approaches to modeling strategic bidding behavior in transmission valuation studies. The first involves the use of a game-theoretic model to simulate strategic bidding [e.g., 13]. Such a model typically consists of several strategic suppliers, with each player seeking to maximize its expected profits by changing its bidding or production strategy in response to the strategies of all other players. The second approach involves the use of estimated historical relationships between certain market variables and some measure of market power such as the difference between estimated competitive prices and actual prices or estimated competitive bids and actual bids (i.e., price-cost markups and bid-cost markups, respectively) [14]. Each modeling approach has its advantages and disadvantages [10]. In assessing these two alternative approaches, we believe that an empirical approach to modeling strategic bidding is preferable to a game theoretic approach if relevant data is available because it can be adapted to a detailed transmission network representation and has been validated through historical experience.

Energy prices that are determined by strategic bidding, i.e., "market prices", have an impact on societal benefits, and often significantly affect transfers of benefits among participants. Because of this, forecasting of market prices is a critical component of the overall transmission evaluation process.

To the best of our knowledge, no entity has successfully developed and implemented a market simulation model based on strategic supply bids[1] while incorporating a detailed physical transmission modeling capability. However, we acknowledge that much research and development remains to be done in this area. The CAISO evaluation methodology does not specify the process to be used for forecasting market power. Rather, at this point, the CAISO requires only that a credible and comprehensive approach for forecasting market prices be utilized in the evaluation. We consider the empirical approach of modeling strategic bidding we used in the Path 26 analysis to be one of several useful methodologies for deriving market prices.

D. Fourth Key Principle: Uncertainty

Decisions on whether to build new transmission are complicated by risks and uncertainties about the future. Future load growth, fuel costs, additions and retirements of generation capacities and the location of those generators, exercise of market power by some generators, and availability of hydro resources are among some of the many factors impacting decision making. Some of these risks and uncertainties can be easily measured and quantified, but others cannot.

There are two fundamental reasons why we must consider risk and uncertainty in transmission evaluation. First, changes in future system conditions can affect benefits from transmission expansion significantly. In general, the relationship between transmission benefits and underlying system conditions is nonlinear. Thus, evaluating a transmission project based only on assumptions of average future system conditions might greatly underestimate or overestimate the true benefit of the

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[1] By "dynamic" we mean that the hourly supply bids change as a function of system conditions. Most of the models that exist currently use a "static" bid strategy (i.e., the bid strategy is set for a period of time such as a month or year and does not change in response to dynamic system conditions such as hourly demand, supply, and import levels). A static bid strategy has difficulty capturing market power that may exist in times of supply inadequacy.

project and may lead to less than optimal decision making. To make sure we fully capture all impacts the project may have, we must examine a wide range of possible system conditions.

Second, historical evidence suggests that transmission upgrades have been particularly valuable during extreme conditions. A large inter-connection between WSCC and the eastern United States during the period June 2000 to June 2001 would have been worth on the order of $30 billion, based on the difference between prices in the two regions. Had a significant inter-connection between the eastern U.S. and WSCC been in existence, prices in the WSCC would not have risen to levels that existed during the period May 2000 to June 2001.

There are several alternative approaches to assessing the impact of risk and uncertainty on transmission expansion [e.g., 3,4]. A complete transmission evaluation process should incorporate stochastic analysis or scenario analysis. Stochastic analysis models the uncertainty associated with different parameters affecting the magnitudes of benefits to be derived from an expansion project. Stochastic analysis often uses probabilistic representations of the future loads, gas prices, and generation unit availabilities.

The economic assessment of a proposed transmission upgrade can be very sensitive to specific input assumptions. Unless the proposed project economics are overwhelmingly favorable when using "expected" input assumptions, we need to perform sensitivity studies using a variety of input assumptions. We do this to compute the following risk measures:

- expected value,
- range, and
- values under specified rare but potentially important contingencies, such as loss of a major transmission link.

Much of the economic value of a potential upgrade is realized when unusual or unexpected situations occur. Such situations may include high load growth, high gas prices, or wet or dry hydrological years. The "expected value" of a transmission upgrade should be based on both the usual or expected conditions as well as on the unusual, but plausible, situations.

A transmission upgrade can be viewed as a type of insurance policy against extreme events. Providing the additional capacity incurs a capital and operating cost, but the benefit is that the impact of extreme events is reduced or eliminated.

E. Fifth Key Principle: Resource Alternatives to Transmission Expansion

The economic value of a proposed transmission upgrade directly depends on the cost of resources that could be added or implemented in lieu of the upgrade. We consider the following resource options:

- central station, renewable, and distributed generation,
- demand-side management,
- modified operating procedures,
- additional remedial action schemes,
- alternative transmission upgrades, and
- combinations of the above.

In addition to considering resource alternatives, another important issue to consider is the decision where to site new transmission. One perspective is that the transmission should be sited after the siting of new generation. The other perspective is that the transmission should be planned anticipating various generation additions. (Sauma and Oren [] carefully analyze these different perspectives.)

We believe the latter perspective is the most efficient approach. Transmission additions have planning horizons that require decisions 8 to 10 years in advance of the line being placed in service. When those decisions are being made, plans to site new generation may not have been made yet. As a result, we believe it best to plan the grid taking into account the profitability of generation additions in various locations. In this way, the transmission planner influences generation decision making, rather than accounting for it after the fact.

The best means to account for the plans of a host of private investment decisions is to model the profitability of the generation decision in the transmission framework. We use a "what if" framework for our standard decision analysis. As an example, if the CAISO were to build a transmission line, what would be the most likely resulting outcomes in the profitability of private generation decisions? Comparing this to a case where we did not build the line, how much would the profitability of generation investment differ? We then optimize generation additions for with and without upgrade cases. The difference in costs between the two scenarios, including both the fixed and variable costs of the new resources, will be the value of the upgrade.

Examining resource alternatives to a transmission upgrade demonstrates that an alternative can either complement the line upgrade or substitute for it.

III. PATH 26 STUDY

In order to illustrate our methodology, we summarize an analysis of a proposed upgrade to Path 26, a major 500 kV path between central and southern California. Figure 1 shows the location of the proposed Path 26 upgrade.

Historically, Path 26 has been frequently congested in the North-to-South direction. We are considering various upgrades to relieve the congestion. For purposes of this study, we defined the Path 26 upgrade project as follows:

- N-S direction – increase from 3,400 MW to 4,400 MW
- S-N direction – increase from 3,000 MW to 4,000 MW

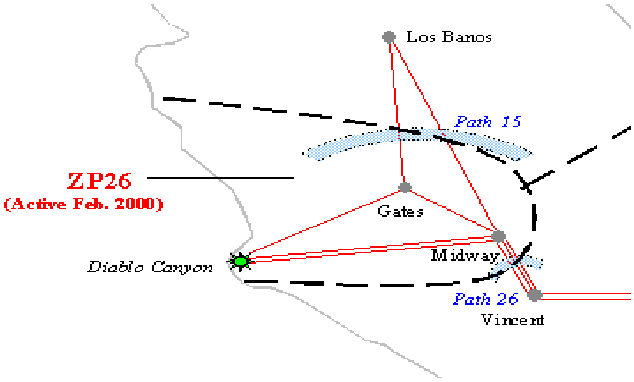

Fig. 1. Location of Proposed Path 26 Upgrade

A. *Market Simulation*

Power production costs and market prices were calculated for the entire WECC using the linear programming-based market simulation package PLEXOS [15]. A linearized DC load flow was included in the model that represented transmission constraints at the 500 kV level, but also flows at lower voltages. LMPs were reported as dual variables from the linear program.

For competitive (cost-based) scenarios, PLEXOS was solved using production (variable O&M) costs as the objective function. For market-based pricing scenarios, assumed bid functions were substituted for production costs for California independent power producers. The bid functions were based on regression analyses relating calculated bid mark-ups to the Residual Supply Index (RSI) and other variables representing market conditions. Bid markups were calculated by comparing actual hourly real-time prices for California's three pricing zones with prices that would result from cost-based bidding. The markups were expressed as a Lerner index $(P_a-P_c)/P_a$, where P_a represents the actual observed price and P_c is the price that would result from price-taking behavior by suppliers. RSI is defined as the ratio of total market supply minus the supply from the largest firm, divided by the load. Only flexible supplies were included, netting out obligations to one's own load and contractual obligations. Likewise, the denominator excluded such obligations from the load. A value of RSI less than 1 indicates that the largest supplier is pivotal, and can push the price up arbitrarily. CAISO experience indicates that RSIs of less than 1.2 are associated with significant markups [14].

An example of a regression relationship used in the Path 26 analysis is:

$$(P_a-P_c)/P_a = 0.14 - 0.53RSI + 0.65LUH + 0.086D_{peak} + 0.15D_{sum}$$

where LUH is the fraction of the load that is unhedged, D_{peak} is a 0-1 dummy variable indicating whether the hour is a daily peak hour, and D_{sum} is a dummy indicating whether it is summer. The R^2 for this estimation was 0.46. The data used to estimate the regressions were from Nov. 1999 to October 2000, and from January-December 2003. These relationships were used obtain bid markups for use in PLEXOS by inserting the appropriate values for the independent variables for each hour and each zone into the equations, rescaling them so that larger suppliers had higher markups. The Path 26 addition of 1000 MW in each direction increased estimated total market supply in the zones it connects, resulting in higher RSIs in the regression equations and, as a result, lower values of $(P_a-P_c)/P_a$.

The amount of markup is necessarily uncertain not only because the regressions were an imperfect fit to the data, but also for several other reasons. These include the following: alternative specifications for the regression equation yield somewhat different markups; overall market price increases are represented in the regressions, which are not identical to bid markups for individual suppliers (for which full data sets were unavailable); and bidding behavior in a zonal market in the present CAISO market design might differ from behavior in a LMP-based market. An LMP market design is planned for implementation in the CAISO in the near future.

B. *Benefit Framework*

The CAISO summarizes four perspectives when evaluating the economic viability of a proposed upgrade. Table I and II summarize the benefits for each of the four perspectives for two different scenarios we developed for 2013. Both indicate the possible distribution of benefits in 2013 for WECC and CAISO, assuming baseline values for load growth, gas prices, hydrological conditions. Table I assumes no market power (cost-based bidding), and Table II assumes baseline bid markups. In addition to the four perspectives shown, we further subdivide the benefits into Consumer, Producer, and Transmission Owner.

The definitions of each of these benefit categories are:

- *Consumer Benefit* – Reduction in cost to consumers.
- *Producer Benefit* – Increase in producer net revenue. For societal perspective, producer benefit includes profit from uncompetitive market prices. For the other three perspectives, this profit is excluded (i.e. monopoly rent).

TABLE I. BENEFIT SUMMARY FOR 2013 UNDER COST-BASED PRICING (BASELINE GAS PRICES, LOAD GROWTH, HYDRO CONDITIONS) [16]

Perspective	**Description**	**Consumer Benefit (M$)**	**Producer Benefit (M$)**	**Trans. Owner Benefit (M$)**	**Total Benefit (M$)**
Societal, Modified Societal	WECC	1.6	1.0	-2.1	0.5
California Competitive Rent	CAISO Ratepayer	-0.8	1.0	-0.8	-0.6
	CAISO Participant	-0.8	1.6	-0.8	0.0

Note: Societal and Modified Societal are the same in the cost-based case as no market power rents exist to be deducted to obtain the Modified Societal results

TABLE II. BENEFIT SUMMARY FOR 2013 UNDER MARKET-BASED PRICING (BASELINE GAS PRICES, LOAD GROWTH, HYDRO CONDITIONS) [16]

Perspective	**Description**	**Consumer Benefit (M$)**	**Producer Benefit (M$)**	**Trans. Owner Benefit (M$)**	**Total Benefit (M$)**
Societal	WECC	34.4	-25.8	-6.6	2.0
Modified Societal	WECC	34.4	-16.9	-6.6	10.9
California Competitive Rent	CAISO Ratepayer	11.1	-4.0	-0.9	6.2
	CAISO Participant	11.1	4.6	-0.9	14.8

- *Transmission Owner Benefit* – Increase in congestion revenue.
- *WECC Societal* – Sum of Consumer, Producer, and Transmission Owner Benefits in WECC. Also equal to difference in total production costs for the "without" and the "with upgrade" case.
- *WECC Modified Societal* – Same as Societal but excludes market power rents from Producer Benefit (differences between profits with and without bid markups).[2]
- *CAISO Ratepayer* – Includes ISO consumers and utility-owned generation and transmission revenue streams.

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[2] For a more complete discussion regarding how total producer benefits are subdivided into competitive and monopoly rents, refer to Chapter 2 of [10].

- *CAISO Participant* – Includes ISO Ratepayer plus the California Independent Power Producer (IPP) Benefit derived from competitive market conditions.

Although the primary purpose of Tables I and II is to illustrate the benefit framework for two of the scenarios, it is informative to understand the reasons for the benefit distributions. In the cost-based bidding scenario of Table I, consumers throughout the west benefited (on average), but California consumers actually paid slightly more for power. In contrast, the consumer benefits were much larger in the market pricing case (Table II), as consumers benefited significantly from a reduction in market power and the more efficient dispatch that resulted from increased transmission capacity. Thus, the market power mitigating effects of transmission are the major source of projected consumer benefits for Path 26. Meanwhile, the Transmission Owner Benefit was *negative* for all perspectives in both scenarios. The Producer Benefit Revenue was also negative for most perspectives -- except for the CAISO Participant perspective (excluding monopoly rents).

Meanwhile, since the proposed Path 26 upgrade reduced congestion and associated congestion revenue, transmission owners saw a significant decline in revenue in both Tables I and II. Finally, producers benefit in the cost-based pricing case (Table I) from the production cost savings made possible by the reinforcement. However, under market-based pricing, the producer benefit was negative for the societal, modified societal, and CAISO ratepayer perspective (Table II). The primary reason for the latter result was that the increased transmission capability enhanced competition in the market pricing case, decreasing revenues more than it decreased costs.

The CAISO IPP competitive benefits (last line), however, increased under both types of pricing. A significant part of that competitive rent increase was due to the increased generation of roughly 10^5 MWh per year by the IPPs in the CAISO area.

C. *Impact of Uncertain Variables*

The cases we developed encompass a wide range of assumptions for selected input parameters. The benefits in some of these scenarios were significantly impacted as a result of changes in the underlying input variable. In other cases, the benefits did not change nearly as much.

Figure 2 summarizes the potential impact of the uncertainty in individual variables on the annual CAISO Participant benefits in 2013 [10]. This "Tornado Diagram" shows the variables with the greatest impact on results in declining order. The impact of three input variables on the 2013 CAISO Participant benefits are shown. The first variable, market pricing, is the level of uncompetitive bidding in the market and ranges from a perfectly competitive market to a highly uncompetitive one. The range of its potential impact is about $26 million, and exceeds the ranges of gas price and demand uncertainties.

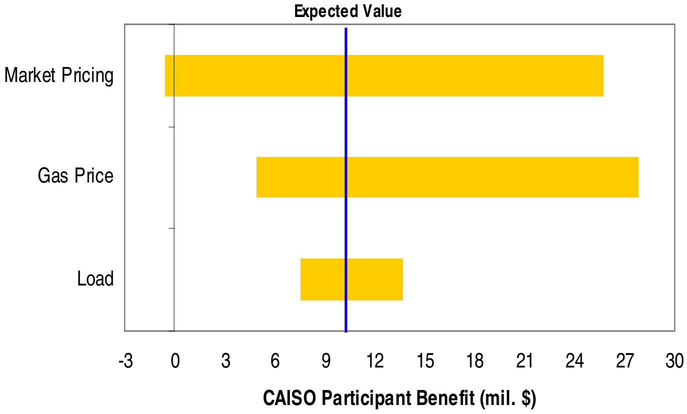

Fig. 2. Tornado Diagram Showing Impact of Single Uncertain Variables, 2013

The low and high load-growth scenarios are based on forecast errors for peak and energy that we computed by comparing historical forecasts and actual conditions. The energy requirement ranges from 180,000 to 200,000 GWh/yr. We also developed low and high gas price scenarios based on observed forecast errors. In 2013, the average burner-tip gas price for WECC is $5.49/MMbtu, while the low and high gas prices are $2.68/MMbtu and $11.25/MMbtu respectively.

D. *Probable Benefit and Cost Range in 2013*

We have estimated a "most-likely" benefit and a "possible" cost range based on the 22 cases for 2013 that have a probability assigned to them. The probability-weighted results of the scenarios are summarized in the histogram shown in Figure 3. The annual CAISO participant benefits for the 22 cases are organized into benefit ranges (or "bins"), each having a range of $5 million dollars. The probability for each benefit range is shown in Figure 3.

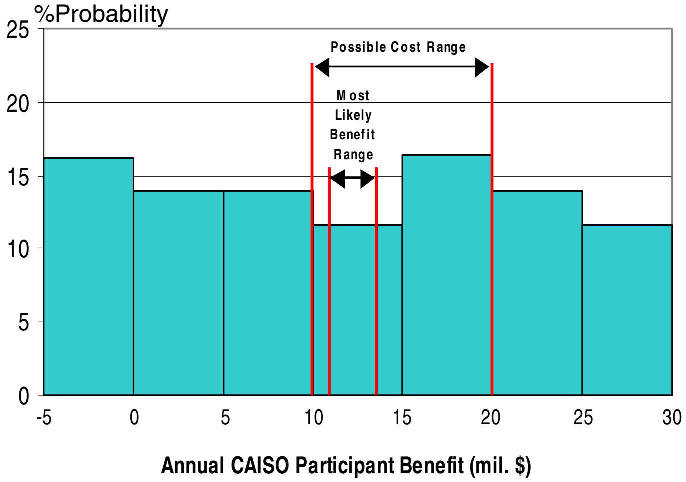

Fig. 3. Potential Range of 2013 Benefits and Costs

A most-likely range of benefits is determined by using a linear programming approach discussed in [10]. Basically, the joint probabilities of demand, gas price, hydropower, and market power scenarios are chosen so that the means and variances of the marginal distributions match the error distributions of historical CEC forecasts (in the case of demand and gas prices), actual production (in the case of hydropower), or a regression model of price markups as a function of market concentration (in the case of markups). Because the correlations of these variables are unknown, there remain several degrees of freedom concerning choice of probabilities. A linear program is used to choose a set of probabilities that results in the maximum expected benefit, subject to the constraints on the marginal distributions. The same linear program, operated in a minimization mode, was also used to find the lower bound on the expected benefit, subject to the same constraints.

Mathematically, a general phrasing of this linear program is:

$$\text{MIN or MAX } \Sigma_{s=1,2,..,S} P_s BEN_s$$

subject to:

$$\Sigma_{s=1,2,..,S} P_s X_{is} = \mu_i, \ i = \text{Gas Price, Load, Hydro}$$

$$\Sigma_{s=1,2,..,S} P_s (X_{is} - \mu_i)^2 = \sigma_i^2, \ i = \text{Gas Price, Load, Hydro}$$

$$P_s \geq 0, \forall i$$

where P_s is the decision variable, representing the probability of scenario s; BEN_s is the societal (WECC) benefit of the transmission reinforcement calculated for scenario s; X_{is} is the value of uncertain variable i in scenario s; μ_i is the expected value across scenarios s of X_{is}; and σ_i^2 is the assumed variance of variable i across s. Application of this linear program in a minimization and then a maximization mode yields the "most likely" range of benefits to CAISO participants shown in Figure 3 [10].[3]

Turning to the possible cost range, we assume that levelized revenue requirements could exceed the levelized capital recovery amount by up to 50 percent (or more). In addition, we assumed that there was a 50 percent uncertainty with respect to the capital cost estimate of $100 million. Applying an appropriate capital recovery factor therefore implies a range for annual levelized costs of between $10 and $20 million.

E. Insurance Value

The benefits in Figure 3 are based on the probability-weighted results from the network simulations (i.e. the difference in benefits for the "without" and "with upgrade" cases). An "insurance value", on the other hand, is a more subjective determination. Developing an appropriate insurance value requires two additional elements: (a) well-defined contingency scenarios to properly understand the extreme-event impacts and associated costs to be avoided; and (b) sufficient input from decision makers to determine their level of risk aversion and their willingness to incur an "insurance" premium to avoid the consequences of these events. Neither of these two elements were available.

We did, however, have an opportunity to develop a contingency case to illustrate the concept of insurance value. We started with a case for the year 2013 where there is high demand, high gas prices, base hydro, and moderate market pricing mark-up. To this case, we assumed that the DC Intertie was unavailable for the entire year.

We consider the yearlong DC Intertie outage to be a contingency case. It is an extreme event, whose probability is not easily quantified, but the occurrence of such an outage could have huge consequences.

As we would expect, in this situation the Path 26 upgrade has more value than any other case evaluated. The CAISO Participant benefit for the DC-out case was calculated to be $32 million in 2013 [10] under moderate demand growth, gas prices, and hydro conditions, and assuming market-based pricing. This value more than doubles under the highest demand and gas price scenarios. Although the *value* of the Path 26 upgrade is substantial in this case, the *expected* value of the Path 26 upgrade in this situation is negligible since the probability of the event is so remote. However, in order to avoid the full consequences of a year-long DC outage, the additional fee that ratepayers (and decision makers) might be willing to pay as an insurance premium could be significantly larger than the expected value, and may be an important part of the overall benefits.

F. Path 26 Recommendation

Based on the results presented in the full report [10,16], we can make the following observations on the annual costs and benefits for the proposed Path 26 upgrade:

- the most-likely CAISO Participant benefits in 2013 range from $11 to $17 million,
- the possible range of estimated costs in 2013 is from $10 to $20 million, and
- the expected range of Modified Societal Benefits in 2013 is $8 to $14 million.

From these observations, we conclude that the Path 26 upgrade *may* be economically viable. However, to reach a definite conclusion in this regard, additional analytical refinements need to be performed. Specifically, these additional refinements would include the following:

- a more detailed estimate of capital costs -- preferably with a 20 percent or less margin of error,
- an appropriate calculation of annual revenue requirements including capital recovery, relevant taxes, operating costs, and other associated costs,
- a more comprehensive evaluation of other Path 26 upgrade alternatives including additional remedial action schemes,
- a net present value analysis of the benefits which would require additional years of benefits to be calculated beyond those for 2008 and 2013, and
- consideration of the potential impact of other projects on the benefits of Path 26 upgrade (and those of other competing projects).

These additional tasks would enable the CAISO and the CPUC to make a more definitive recommendation regarding the economic viability of the proposed Path 26 upgrade.

IV. CONCLUSION

Based on our initial use of the TEAM methodology in the case

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[3] Subsequent analysis under revised assumptions expanded this range somewhat to $11M to $17M [16]. Total Societal Benefit had a most likely range of $2M to $3M; Modified Societal Benefit had a range of $8M to $14M; and Total CAISO Ratepayers Benefit had a range of $5M to $9M.

study of Path 26, we conclude that the methodology and its five guiding principles will substantially enhance the CAISO's ability to fulfill its responsibility to evaluate and recommend transmission expansion projects.

The case study results demonstrate that the methodology will produce the comprehensive analytical information that project proponents and review and approval authorities need to make informed decisions in shaping California's transmission infrastructure. The TEAM methodology advances this objective by creating a framework to examine a project from multiple viewpoints — from those of the overall western interconnection, to the consumer or transmission line owner. Equally important, the methodology provides a flexible mechanism to identify a range of risks and rewards associated with the project under diverse contingency and market conditions.

We believe that adopting TEAM as a standard for all California parties to use in evaluating the economic need for transmission projects would promote consistency and comparability and eliminate duplicative studies.

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