The California ISO Transmission Economic Assessment Methodology

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Abstract—**In response to the novel requirements that competitive power markets place upon transmission planning, a method for assessing the economic benefits of transmission reinforcements is proposed for California. Economic benefits considered include reductions in the cost of constructing and operating power plants, along with mitigation of market power by improving supplier access to markets. 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.**

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

I. INTRODUCTION

THE need for new transmission planning processes that are responsive to the new demands of a restructured power industry is widely acknowledged [1-8]. Economic analyses of potential transmission reinforcements need to recognize multiple perspectives when estimating benefits; the market behavior of generators and consumers on the network; uncertainty; and alternatives to transmission; The California Independent Operator (CAISO) has developed a planning approach that considers these elements [9].

The CAISO is responsible for evaluating the need for all potential transmission upgrades that California ratepayers may be asked to fund.[1] 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. To fulfill its responsibility for identifying economic projects that promote efficient utilization of the grid, the CAISO has developed a methodology called the Transmission Economic Assessment Methodology (TEAM)[2].

The CAISO has consulted with many stakeholders including the California Public Utilities Commission (CPUC), the California Energy Commission (CEC), and California electric utilities in formulating this methodology. The goal of TEAM is to significantly 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. To this end, the CAISO has filed this methodology for consideration in the CPUC's ongoing transmission investigation preceding commenced pursuant to Assembly Bill 970.[3]

Depending on the environmental and economic attributes of a proposed transmission project and the project sponsor, a number of agencies can have planning, review, oversight and approval roles. These agencies range from the CAISO, the CPUC and the CEC to the boards of municipal districts and utilities. 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. Both the CEC and CPUC have recognized that this process has led to redundancies and inefficiencies [10,11]. 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, less contentious and more widely supported decisions on key transmission investment projects.

This paper presents a methodology for assessing the economic benefits of transmission expansions for market environments in the face of uncertainty. It also summarizes a demonstration of the methodology in the form of an application

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[1] The California Legislature, pursuant to Public Utilities Code § 345, assigned the CAISO the responsibility of "ensur[ing] [the] efficient use and reliable operation of the transmission grid." To achieve this goal, the CAISO can compel Participating Transmission Owner's to pursue construction of transmission projects deemed needed either to "promote economic efficiency" or to "maintain system reliability" (CAISO Tariff § 3.2.1.)

[2] The terms TEAM and CAISO methodology are used interchangeably throughout this paper.

[3] Phase 5 of "Order Instituting Investigation into Implementation of Assembly Bill 970 Regarding the Identification of Electric Transmission and Distribution Constraints, Actions to Resolve those Constraints, and Related Matters affecting the Reliability of Electric Supply," I.00-11-001.

to a proposed transmission expansion between central and southern California called Path 26. 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 for reliable and efficient delivery of electric power to California consumers.

Restructured wholesale electricity markets require a new approach for evaluating the economic benefits of transmission investments. Unlike the previous vertically integrated market where one 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 expansions. Specifically, the new approach must address what impact a transmission expansion would have on increasing transmission users' access to sources of generation and customers requiring energy, what incentives it would create for new generation investments, and what impact it would have on market competition. The approach must also account for the inherent uncertainty associated with key market factors such as future hydro conditions, natural gas prices, and demand growth. Our challenge has been integrating all of these critical modeling requirements into a comprehensive methodological approach.

The TEAM methodology represents the culmination of over two years of research and development led by the CAISO with support and input from industry experts and the CAISO Market Surveillance Committee. It integrates five key principles for defining quantifiable benefits into a single comprehensive methodology to support decisions about long–term investments required for transmission upgrades. We believe the methodology provided here represents the state-of-the-art in the area of transmission economics 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. While this methodology specifies what the basic facets of a comprehensive transmission study should be, it makes no specific recommendation on a particular software product to use in its application. It does, however, provide standards on the minimum functional requirements the modeling software should have.

II. TRANSMISSION DECISION PROCESS IN CALIFORNIA

A. CAISO Decision Process

The need for a major transmission upgrade can be identified by a number of parties including utilities; public or private project developers, the CEC through its long-term resource studies, and the CAISO as the transmission operator. We are offering the TEAM framework as consistent means of conducting a project evaluation by any of these parties. If a sponsor does not privately finance a project, and a proposal is submitted to the CAISO for funding through an access charge, the CAISO will utilize the TEAM framework to evaluate project economics. The project must receive a favorable evaluation prior to us recommending the CAISO Board approve it.

We will also evaluate other perspectives to determine if other parties will benefit from the potential upgrade and can contribute to the capital cost of the upgrade. This evaluation will help us identify if large amounts of benefits transfer from one region to another or one market participant to another. Although not everyone may be compensated for a change in regional prices, the ultimate aim of an upgrade is to improve productive efficiency so all load may be served at a lower cost. The CAISO will primarily rely on two perspectives when evaluating the economic viability of a potential transmission upgrade. These two perspectives are the Modified Societal and the CAISO Participant. The Modified Societal perspective evaluates whether an upgrade is economic from a regional perspective (excluding the generator profits from uncompetitive market prices). The CAISO Participant perspective evaluates whether an upgrade is economic for the participants in the CAISO market (also excluding the generator profits from uncompetitive market prices). For each of these perspectives, there are expected to be WECC and CAISO winners and losers, but if the overall perspective is positive, then the project is a good candidate for further evaluation incorporating additional decision criteria.

B. CA Regulatory Framework for Transmission Evaluation

The regulatory process and procedures related to bulk electricity transmission assets can be divided into three sequential categories: planning, siting and ratemaking. The regulatory or oversight body responsible for each category depends on the identity of the particular project sponsor, i.e., public utility or investor-owned utility ("IOU").

Publicly owned utilities, such as municipal and special district utilities, continue to operate under the vertically integrated business-model and obtain planning approval, siting and environmental review, and rate authority from their local regulatory authority ("LRA"). As the result of industry restructuring, IOUs and other utilities that have joined the CAISO ("Participating Transmission Owners" or "PTOs") participate in the CAISO's Grid Coordinated Planning Process. IOU projects identified and approved by the CAISO in the planning phase continue to undergo environmental review and receive siting approval from the CPUC prior to construction. Jurisdiction over PTO transmission rates and terms of service passed to the federal government under restructuring and is administered by the CAISO through the Federal Energy Regulatory Commission ("FERC").

The CAISO's Grid Coordinated Planning Process evaluates transmission expansion projects that serve three main functions:

- Interconnecting generation or load
- Protecting or enhancing system reliability
- Improving system efficiency and flexibility, including reducing congestion

The CAISO intends to apply the TEAM methodology in evaluating interconnection and system efficiency projects. Under established FERC interconnection policy, PTOs must reimburse an interconnecting generator within five years for any "Network Upgrades" paid for by the generator. Because the interconnecting generator receives its money back within five years, the incentive for generators to select the least-cost location from an interconnection perspective is reduced. In response to this perceived inefficiency, the CAISO has proposed to use the TEAM methodology to determine the benefits of network upgrades for purposes of establishing a "cap" on the level of compensation available to the interconnecting party.

For system efficiency projects, the CAISO is authorized to compel PTOs to construct transmission expansion projects that promote economic efficiency. The CAISO tariff only includes general instructions to PTOs and other market participants on providing information, including studies in accordance with "CAISO guidelines," that enable the CAISO to determine whether a project will promote economic efficiency. The TEAM methodology will serve as the CAISO "guidelines."

As part of its siting responsibility, the CPUC has historically reviewed whether a project was necessary for reliability or economic reasons. Some have criticized this review as duplicative of the CAISO' determination reached in its Grid Coordinated Planning Process. The CPUC is currently proposing to eliminate duplicative transmission need determinations by deferring to the need assessments reached by the CAISO to the extent the CAISO applies agreed upon economic and reliability standards. The TEAM methodology represents the anticipated standards to be applied in evaluating economic projects in CPUC proceedings.

III. MAJOR CHALLENGES AND SOLUTIONS

This evaluation method was developed to capture the quantifiable economic benefits of transmission expansion in the current restructured wholesale market environment. In areas served by ISOs/RTOs, these institutions have the responsibility for providing non-discriminatory access to all parties. Their planning and evaluation of transmission augmentations must be consistent with this objective. It must also account for the fact that investment in new generation resources is made in the market place by private companies or by utilities subject to regulatory oversight, with the focus on the profitability to the investing party. Planners at an ISO or RTO must consider broader objectives that integrate the benefits of the grid to all participants in the region including retail customers, generation owners, and transmission owners.

The experience of many ISO/RTOs that have locational marginal prices (LMP) is that the prices differences between locations may not be sufficient to spur investment in transmission upgrades. The theory behind locational marginal prices is that generation or load would sign contracts to deliver the power to load and those contracts would provide the revenue source for upgrades to the transmission grid. But the reality has been that the LMP differences have not provided enough incentives to upgrade key facilities even after many types of FTR's and CRR's are provided. Our new methodology recognizes that there are many "public goods" aspects to transmission investments, making them similar to investments in the freeway system: (1) they are very lumpy in size, (2) there is non excludability in their use, since an upgrade to an AC grid means many parties who use the grid will benefit, and we cannot exclude parties from benefiting once an upgrade is in place, and (3) there are many positive externalities associated with the upgrade such as generators and consumers in many parts of the network may be affected. A methodology is needed that correctly accounts for the public good aspect of transmission investment.[4]

In a restructured market place, power suppliers are bidding to maximize their profits rather than simply to recover their operating costs. In this market-oriented environment, an ISO/RTO must consider the risk of market power and how a transmission expansion can serve to reduce this risk. Even after considering other market power mitigation measures such as a market price cap, automated mitigation procedures (AMP) on bids, and long-term contracts, a transmission expansion can provide market power mitigation benefits through enlarging the market and reducing the concentration that any one supplier may have under a variety of system conditions.

Uncertainty in load growth, hydro conditions, availability of imports, and new generation entry levels can have significant impacts on the economic benefits of a transmission expansion to different parties and regions. Therefore, it is critical that a valuation methodology explore the economic value of a transmission expansion under a number of different assumptions about future market conditions, particularly extremely adverse market conditions (e.g., high demand and low hydro).

To address these challenges, the new transmission valuation methodology we propose here offers five major enhancements to traditional transmission evaluations. It:

1. Utilizes a framework to consistently measure the benefits of a transmission expansion project to various participants. It provides policy makers with several options or perspectives on the distributional economic impacts of an expansion on consumers, producers, transmission owners or other entities entitled to congestion revenues), distinguishing congestion within and between regions
2. Utilizes a network model[5] that can capture the physical constraints of the transmission grid as well as the economic impacts of a project
3. Provides a simulation method that incorporates the impact of strategic bidding on market prices. This allows the benefits of transmission expansions to be not limited solely to reducing the production cost of electricity but also to include consumer benefits from reduced supplier market power
4. Addresses the uncertainty about future market conditions by providing a methodology for selecting a representative set of market scenarios to measure benefits of a transmission expansion and provides a methodology for assigning weighting factors (relative probabilities) to different scenarios so that the expected benefit and range of benefits for a transmission expansion can be determined
5. Captures the interaction between generation, demand-side management, and transmission investment decisions rec-

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[4] Public goods are defined as a shared good for which it is impractical to make users pay individually and to exclude non- payers.

[5] The "network model" used in this methodology is not an AC model in that it does not explicitly model the reactive power and voltage interactions with real power flow and phase angles. However, it provides for explicit computation of transmission losses (which are allocated based on pre-specified loss allocation factors). In this sense, it can be classified as a linearized DC power flow model. Transmission constraints are enforced explicitly on EHV transmission paths.

ognizing that a transmission expansion can impact the profitability of new resources investment, so that a methodology should consider both the objectives of investors in resources (private profits) and the transmission planner (societal net-benefits)

Finally, our proposed methodology is intended to be sufficiently general in application so that it can be used by project participants, non-participants, and regulators in evaluating transmission projects over a broad spectrum of energy-industry environments -- ranging from a traditional utility service territory operation to large geographical areas with nodal markets. Although the CAISO may play a central role in transmission expansion in California by funding the critical expansion through ratepayer grid access charges, the proposed evaluation methodology will not preclude private investment in transmission projects. The TEAM approach will identify all beneficiaries of a proposed upgrade. The question of who should fund it should be dealt with separately.

IV. KEY PRINCIPLES OF THE EVALUATION METHODOLOGY

There are aspects of our methodology we consider critical for any economic evaluation of transmission upgrades. We call these aspects *"key principles*". Several of these principles have previously been identified by researchers as being essential to transmission planning in market environments, especially the consideration of market operations, uncertainty, and alternatives to transmission [2-8]. However, no previous methodologies have explicitly considered how transmission reinforcements could affect strategic behavior (market power), and how that behavior affects the benefits of transmission.

Other aspects of our methodology are evolving as the modeling and analytical technology improves. We identify these *"potential enhancements"* later in this paper. Many of the evolving components are good candidates for further research and development by the CEC, CPUC, or other parties. Finally, there are elements that were required for the study, but which were not specified by the CAISO. We refer to these elements as *"user-selected components."*

Although the 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.

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. This benefit framework provides decision makers a useful tool for assessing transmission benefits in a consistent and effective manner.

We intend that the benefit framework provide a structure for summarizing the benefits, costs, and risks of the proposed transmission upgrade to the decision makers. The framework should be consistent from one study to another so that alternative project investments can be evaluated against a common standard. The benefit framework should also be able to present the relative economics of a project from a variety of perspectives –consumer, producer, and transmission owner, and on a societal or regional basis.

Consumer benefits in a vertically integrated utility come from three sources -- the reduction in consumer costs, the increase in utility-owned generation net revenue, and the increase in utility-derived congestion revenue. In our methodology, 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 consumer, producer, or transmission owner benefits. Negative numbers indicate a decrease in benefits.

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, which 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 producer and consumer region to another.

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

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, the Market Surveillance Committee and the Electricity Oversight Board have argued that it is reasonable to exclude the loss of monopoly rents in the benefit calculations.[6] This is the key

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[6] This does not mean producers collect only variable costs. Since this is a long-run analysis, both variable and fixed cost of production is accounted for. The profitability of generation is assured through a revenue test for all supply.

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 locational prices.

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 uneconomical 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 not correctly 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.[7]

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 trade-offs, 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:

- 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.
- Capable of modeling and enforcing individual facility limits, linear nomograms, and path limits.
- Capable of modeling limits that vary based on variables such as area load, facility loading, or generation availability.
- Capable of modeling only those limits of interest (typically only 500 kV and selected 230 kV system limits)
- Models phase shifters, DC lines, and other significant controllable devices
- Capable of calculating nodal prices.
- Capable of plotting the hourly flows (either chronologically or by magnitude) on individual facilities, paths, or nomograms.
- While not required, it is desirable for the simulations to model transmission losses.

While our methodology requires the 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. To the extent that cases conducted using a simplified model are critical to the economic support of a transmission project, the results of this analysis should be confirmed using a network model.

C. Third Key Principle: Market Prices

Historically, resource-planning studies have typically relied on production cost simulations (i.e., marginal cost pricing) 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. Assuming marginal cost pricing in a restructured market environment where suppliers are seeking to maximize market revenues may result in inaccurate 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 market competitiveness by both increasing the total supply that can be delivered to consumers and the number of suppliers that are available to serve load.

There are two approaches to modeling strategic bidding behavior in transmission valuation studies. The first approach involves the use of a game-theoretic model to simulate strategic bidding [e.g., 12]. A game theoretic model typically consists of several strategic suppliers with each player seeking to maximize its expected profits by changing its bidding strategy in response to the bidding 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) [13]. Each modeling approach has its advantages and disadvantages. We discuss these in detail in the full report [9]. In assessing these two alternative approaches, we believe 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 have a significant impact on the transfer of benefits among participants. Because of this, forecasting of market prices is a critical component of the overall transmission evaluation process.

Forecasting of market prices is a difficult task. It requires us to predict the market behavior of certain suppliers (i.e., strategic bidders) under a variety of system conditions. Our task is

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[7] For purposes of TEAM, a network model does not necessarily require modeling flows on lower voltages lines (i.e., 69, 115, and some cases 230 kV) or lower voltage constraints.

further complicated by our decision to use a highly detailed representation of the transmission network (i.e., a network model of the entire WECC). For the most part, software models to date have either focused on transmission modeling and neglected the market behavior side, or focused on the market behavior aspect without the detailed transmission representation.

To the best of our knowledge, no entity has successfully developed and implemented a market simulation model based on dynamic supply bids[8] and incorporating a detailed physical transmission modeling capability for a reliability region. The CAISO methodology includes these important attributes. The coupling of a dynamic bidding capability with a network model is an important step forward and an essential component of the CAISO methodology. 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, and some 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. Historically the relationship between transmission benefits and underlying system conditions was found many times to be 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 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. The chair of the CAISO's Market Surveillance Committee estimated that 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 (F.A. Wolak, personal communication). 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. In addition, it would have perhaps avoided the recent blackout in the eastern U.S. that led to significant economic loss in that area of the country.

There are several alternative approaches to assessing the impact of risk and uncertainty on transmission expansion [e.g., 3,4]. The most often used in practice are the deterministic approach, the stochastic approach, or a combination of the two. Deterministic analysis is performed using point estimates. These estimates may be, for example, a single set of assumptions about loads, natural gas prices, and the availability of generating plants to meet customer loads. Deterministic analysis is useful for understanding a single set of input forecasts. It does not measure the impact of risk and uncertainty. As such, it is best used for initial analysis of an expansion proposal. 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 benefit measures:

- Expected value
- Range
- Contingency value(s)

A significant portion 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 Alternative to Transmission Expansion

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

- Central station generation
- Demand-side management
- Renewable generation and distributed generation
- Modified operating procedures
- Additional remedial action schemes (RAS)
- Alternative transmission upgrades
- Any combination of the above

In addition to considering the resource alternatives described

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[8] 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.

above, 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.

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 yet have been made. As a result, we believe it best to plan the transmission 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 different 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.

A third issue we face is whether to credit the proposed transmission upgrade with the benefit of resource alternatives that are economic in the "with upgrade" case, but are not viable in the "without upgrade" case. We have concluded that these benefits are properly attributed to the transmission upgrade that facilitated such investment.

V. APPLICABILITY OF METHODOLOGY

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.

For all transmission upgrade studies, we will require as a minimum, the use of a transmission network model and the consideration of alternative resources. In certain situations where the impact is primarily limited to a single utility, these two requirements may be sufficient. In other cases, a more comprehensive analysis including the full benefit template, forecasting market prices, and understanding the uncertainty of the benefits will be necessary.

For example, suppose a utility wants to evaluate a transmission upgrade internal to its system. If the utility has correctly modeled the impact of this upgrade on outside parties and found that the impact is primarily limited to its system, then the full benefit template would not need to be employed. In this case, a utility perspective would be sufficient.

In those cases where there is a physical or contractual impact on other parties, a full benefit template needs to be developed in order to better understand the economic impact on other participants. If preliminary economic feasibility studies show the proposed upgrade to be strongly economic from both a societal and participant perspective (e.g. the CAISO), then uncertainty analyses may not be necessary. If, however, the economic benefits are marginal, uncertainty analyses may be needed to better understand the distribution of benefits and their root causes.

VI. POTENTIAL ENHANCEMENTS

As we stated at the beginning of this paper, the CAISO-proposed methodology is based on five key principles. Although we established these principles as requirements, their exact implementation is not fixed. Our Path 26 study has provided us the initial opportunity to evaluate how to implement our methodology in a realistic situation. It has also given us the experience on which to base suggestions for further enhancements.

Below is a summary of potential enhancements we have identified, organized by the five key principles. While this is not an exhaustive list, it provides an indication of the type of enhancement that could create additional analytical value.

Benefit Framework Principle:

a) Enhance methodology to handle companies and sub-regions that will continue to plan on contract path basis (e.g. LADWP).
b) Greater disaggregation of participant benefits to company level.

Network Representation Principle:

a) Review impact and trade-offs involved in modeling select 230 kV lines and develop recommendation for 230 kV line inclusion.
b) Develop methodology to Include losses and wheeling charges.
c) Develop greater understanding of phase shifter operations and model accordingly.

Market Prices Principle:

a) Enhance residual supply index (RSI) methodology by considering mark-ups in non-CA regions and alternative regression forms.
b) Review and test alternative approaches for forecasting market prices including game theory.

Uncertainty Principle:

a) Evaluate ways to streamline approach so that more sensitivity cases can be run
b) Develop probabilities for hydro and under- and over-build scenarios.

Resource Alternatives Principle:

a) Develop more resource alternatives to evaluate including renewable and demand-side resources.

Other Enhancements:

a) Add unit commitment, short-term load forecast uncertainty, and partial heat rate data
b) Optimize hydro storage subject to constraints
c) Disaggregate generator data further to represent generators by unit instead of plant.

VII. USER-SPECIFIED COMPONENTS

In addition to identifying what analytical steps we consider required and which ones are evolving, we believe it equally important to note what components of the CAISO methodology we are not specifying in detail. We have intentionally not specified a detailed analytical methodology with respect to certain "user-specified components" of the study, which we believe are best, decided by the end-user or sponsor of the study.

Below are summarized the user-specified components, organized by key principle:

Benefit Framework Principle:

a) Number of study years, discount rate, revenue requirements calculation
b) Interpolation or extrapolation of benefits

Network Representation Principle:

a) Type or vendor of network model
b) Source of underlying transmission or generation data

Market Prices Principle:

a) Empirical or game-theory approach
b) Regression formulation for empirical approach

Uncertainty Principle:

a) Number and specification of sensitivity studies
b) Input data and probability for sensitivity studies

Resource Alternatives Principle:

a) Specific resource alternatives
b) Transmission operating alternatives

VIII. RELIABILITY AND OPERATIONAL CONSIDERATIONS

A. *Reliability Evaluations and TEAM Methodology*

The TEAM methodology can be applied to both reliability-driven and market-driven transmission expansion/upgrade projects in the following ways.

The reliability-driven projects (called "reliability" projects for short) typically include a set of alternative projects. All are identified as technically viable in addressing an existing or anticipated threat to reliable operation of the power system. At least one of must be selected based on its relative economic merits compared to the other candidate alternatives. Here, the objective of economic analysis is to identify the most cost-effective alternative. This means that even if none of the identified projects has quantified benefits that exceed the quantified costs, we would not reject the most cost-effective alternative solely because it was not economically viable with respect to the identified costs and benefits. This is because "operational reliability" has dimensions that are not uniquely measurable in monetary terms (e.g., the value of avoiding the adverse socio-political ramifications of a system-wide blackout is at best subjective).

For the "reliability" projects, the TEAM methodology is intended to complement existing reliability studies and determine the additional economic benefits derived from an upgrade. In general, these benefits can include improvements in market competitiveness, decreases in fuel and capital costs of generation, and decreased probability and severity of service interruptions. The TEAM methodology is designed primarily to assess the first two categories of benefits, termed "economic benefits." In short, for "reliability" projects, the methodology is used to compare relative economic viability of candidate projects, all of which satisfy reliability objectives.

Market-driven projects (called "economic" projects for short) are candidate projects that are not necessary to maintain the reliability of the system operation but are important to facilitate market transactions and help mitigate strategic market behavior. For example, even if adequate resources were available in a load pocket, in the absence of strict regulatory measures, the load in that local area may still face curtailment risk if all local resources belong to a single entity in a position to exercise market power through physical withholding. Alternatively, a local supplier may engage in economic withholding with attendant high costs to the consumer. For "economic" projects, it is essential to quantify the benefits of the project (in monetary terms) with a metric that measures the magnitude of departure from a purely competitive (cost-based) market outcome with and without the project.

Moreover, the decision as to whether or not to proceed with a given "economic" project will hinge upon the identified economic benefits of the project exceeding its identified economic costs. If several alternative "economic" projects are identified, the TEAM methodology will assist in determining those candidates that are economically viable, and in identifying the most cost-effective project among them. For projects requiring an economic justification for the upgrade, we assumed that a resource adequacy mechanism is in place to ensure that reliability objectives of the grid were satisfied. Thus, the approach is used to compare relative economic viability of candidate projects, all of which satisfy reliability objectives.

B. *Cost-Effective Solutions to Operational Concerns*

Reliable power system operation requires adequate supply, adequate transmission, and adequate communication and control. In the integrated utility environment, a single entity had the responsibility for infrastructure adequacy. However, in the deregulated environment with transmission open access and reduced control by the power system operator of supply participation in the market, inadequacies or flaws in market design and rules can impact operation of the grid. For example, the inadequacy of the existing CAISO market design allows generation to schedule in the forward market in locations where there is inadequate transmission. By relying on scheduled generation that cannot be delivered due to transmission constraints, the system operator can face a number of daily operational problems that, if not addressed early, can result in increased reliability risk. Strictly speaking, this is not a reliability risk due to inadequate transmission, but due to inadequacy of market design.[9] There may have been adequate supply else-

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[9] Transmission planning studies for reliability projects start from a base case assuming all resources are available, and then consider conditions arising from credible contingencies such as the loss of the largest generator and an N-1 outage on the transmission grid. If the system is secure under these conditions, then it is expected to be secure under normal, operating conditions. The events considered in these planning studies include more probable multiple simultaneous events: those that have occurred three times within ten years. This criterion is used to determine reliability. Inadequate transmission reliability means the criterion of N-1 contingency is not met. If this were the case, a reliability based upgrade would be requested. Inadequate transmission capacity may have

where that the operator could have lined up in the forward market without risking real-time transmission congestion.

Although transmission expansion could reduce the operational reliability risk in this case, transmission inadequacy is not the root of the problem, and transmission expansion may not be most the cost-effective response. In this case, the operational concerns arose out of flawed market design. The benefit of the upgrade could be entirely different depending on whether or not the market design flaw is rectified. In order to identify the most cost effective solution to an operational problem it is important to distinguish between a reliability problem on the gird that should be addressed through a reliability upgrade and an operational concern arising from market design flaws.

Another example of distinguishing between reliability problems and poor economic incentives as being the root cause of operational problems is the inadequacy of rules regarding generation interconnection. If policy allows a generator to be built without regard to transmission system adequacy, it is conceivable that after a power plant is constructed, transmission would be inadequate to allow its supply to get out and serve load. A better generation interconnection policy would have had either the generator or another entity responsible for upgrading the transmission system to accommodate the new generation. A combination of inadequate generation interconnection policy and flawed market design can give rise to operational problems that may have nothing to do with transmission inadequacy. Even if generation were built where it could not be delivered in full due to transmission constraints, it may still be possible to entirely avoid operational reliability risk by proper market design (e.g., forward market scheduling taking into account "intra-zonal congestion") without the need for a transmission upgrade. Insufficient operational reliability due to market design flaws is not a justification for a transmission upgrade when market design improvements (e.g., the ongoing CAISO Market Redesign and Technology Upgrade process) are anticipated that will correct the reliability problem. As stated in the previous section, our methodology recognizes the distinction between grid reliability upgrades and economic upgrades needed to accommodate market transaction to bring the most cost-effective solution forward for consideration.

IX. PATH 26 STUDY

A. *Study Description*

In order to illustrate our methodology, we include a summary of an example study that we conducted using the methodology. The example we selected is a proposed upgrade to a major 500 kV path between central and southern California [Path 26]. 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:

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

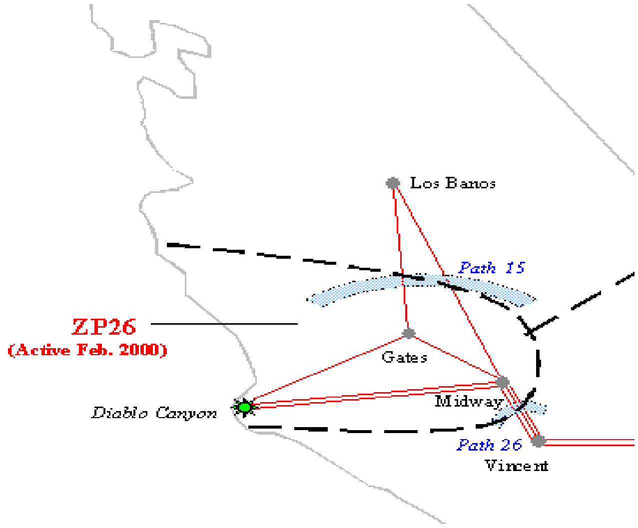

Fig. 1. Location of Proposed Path 26 Upgrade

B. *Benefit Framework*

The CAISO summarizes four perspectives when evaluating the economic viability of a proposed upgrade. Table I summarizes the benefits for each of the four perspectives. The results shown in Table I represent one of the scenarios we developed for 2013. This particular scenario indicates the possible distribution of benefits in 2013 for WECC and CAISO assuming baseline input variables for load growth, gas prices, hydrological conditions, and bid mark-ups. In addition to the four perspectives shown, we further subdivided the benefits into Consumer, Producer, and Transmission Owner.[10]

TABLE I. BENEFIT SUMMARY FOR TYPICAL 2013 SCENARIO[11]

Perspective	**Description**	**Consumer Benefit (mil. $)**	**Producer Benefit (mil. $)**	**Trans. Owner Benefit (mil. $)**	**Total Benefit (mil. $)**
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

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).

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nothing to do with violation of reliability criteria, but be the result of inadequate capacity to meet the demand for lower cost market transactions.

[10] Power production costs and market prices were calculated for the entire WECC using the linear programming-based market simulation package PLEXOS [14]. 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.

[11] Source: [15]. This scenario is the 2013 market-based reference case, which uses base assumptions for demand, gas price, hydro, and mark-up.

- *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 Producer Benefit derived from uncompetitive market conditions
- *CAISO Ratepayer* – Includes ISO consumers and utility-owned generation and transmission revenue streams
- *CAISO Participant* – Includes ISO Ratepayer plus the CA Independent Power Producer (IPP) Benefit derived from competitive market conditions

Although the primary purpose of Table I is to illustrate the benefit framework for one of the scenarios, it is informative to understand the reasons for the benefit distribution. In this particular scenario, the Consumer Benefit was *positive* for all perspectives and the Transmission Owner Benefit was *negative* for all perspectives. The Producer Benefit Revenue was also negative for most perspectives -- except for the CAISO Participant perspective (excluding monopoly rents).

These results appear reasonably intuitive. The consumer benefited significantly from a reduction in market power and the increased transmission capacity resulting in a more efficient generation dispatch. Meanwhile, since the proposed Path 26 upgrade reduced congestion and associated congestion revenue, transmission owners saw a significant decline in revenue.

The producer benefit was negative for the societal, modified societal, and CAISO ratepayer perspective. The primary reason for this reduction in net revenue was that the increased transmission capability resulted in a more efficient generation dispatch which then resulted in lower prices paid to generators.

The CAISO IPP competitive benefits, however, increased by \$12 million. A significant part of the competitive rent increase was due to the increased generation of approximately 120 GWh per year by the IPPs in the CAISO area.[12]

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 of individual variables on the annual CAISO Participant benefits in 2013. This figure is often referred to as a "Tornado Diagram" in that it visually displays the results of a single-factor sensitivity analysis. In a Tornado Diagram, generally the variables with the greatest impact on results are shown in declining order.

Figure 2 shows the impact of three input variables on the 2013 CAISO Participant benefits. 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 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 per year.

We also developed the gas price low- and high-price scenarios based on an observed forecast error. In 2013, the average burner-tip gas price for WECC is \$5.49/mmbtu. The low and high gas prices in 2013 are \$2.68/mmbtu and \$11.25/mmbtu respectively.

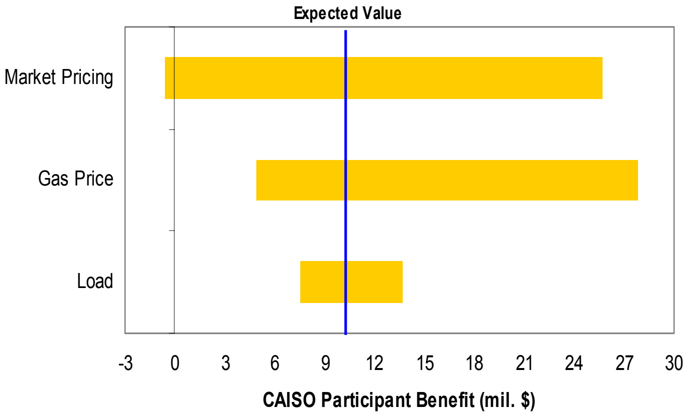

Fig. 2. Tornado Diagram Showing Impact of Single Uncertain Variables, 2013[13]

The potential impact on the annual CAISO Participant benefit from the uncertainty surrounding market pricing was about \$26 million in 2013. The impact from uncertain gas prices was approximately \$23 million, and the impact from uncertain load growth was \$6 million.

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"). The benefit range in Figure 3 is \$5 million nominal dollars. The collective probability for all cases in each benefit range are totaled and shown in Figure 3.

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[12] For a more complete discussion regarding how total producer benefits are subdivided into competitive and monopoly rents, refer to Chapter 2 of the full TEAM Report [9].

[13] The cases considering the impact of a low and high hydrological condition for 2013 assuming a base mark-up have not been reviewed yet, and are therefore not presented at this time.

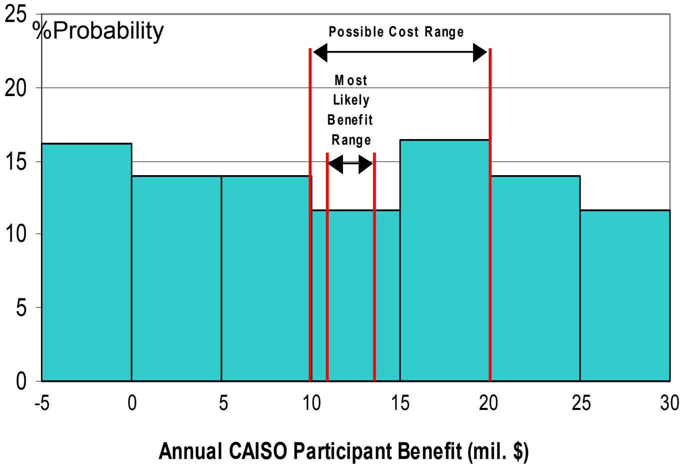

Fig. 3. Potential Range of 2013 Benefits and Costs

A most-likely range of benefits is determined by using a linear programming approach discussed in [9]. 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.

For the possible cost range, we recognize that the 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. Therefore, we believe that a reasonable range for annual levelized costs is 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 sufficiently available in this study to compute an insurance value.

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 $80 million in 2013. 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 yearlong 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 [9], 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 $14 million
- The possible range of estimated costs in 2013 is from $10 to $20 million
- The expected range of Modified Societal Benefits in 2013 is $7 to $10 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 (RAS)
- A net present value analysis of the benefits which would require additional years of benefits to be calculated beyond those for 2008 and 2013
- 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.

X. CONCLUSION

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