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A Consolidated Madm Method under Uncertainly for Strategic Resource Planning

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Abstract: This paper presents an integrated MADM methodology for handling multi-attribute planning under uncertainty, which combines the attractive features of utility function model and tradeoff/risk analysis, two most commonly used decision methods in the utility industry. It is within the framework of tradeoff/risk analysis but introduces a novel multi-dimensional numerical knee-set searching algorithm based on the measure of composite distance, a special form of utility function model. Statistical background is provided for the selection of appropriate tolerance levels with which a range of acceptable plans or the conditional decision set can be determined. A sample study concerning with the optimal design of grid-linked renewable energy systems is provided to illustrate the concept of proposed decision methodology.

Key words: Decision Making · Utility Industry · Tradeoff/risk analysis · Utility functional Model

INTRODUCTION

For many years, uncertainty has been a major issue faced by electric power industry in their strategic planning. Some of the primary data, such as demand growth, fuel prices, capital costs, and regulatory standards, may have a profound influence on the course and outcomes of utility resource development, and it is very difficult to provide definite data as these parameters themselves are influenced by many uncertain conditions. For instance, the uncertainties associated with future demand forecasts could make the system generation facilities inadequate or excessive, both cases being unacceptable. In recent years, competitive markets are adding new uncertainties that make responsible decision-making for generation and transmission expansion projects more difficult. For instance, uncertainties in competitive generation capacity additions in terms of the Sitting, timing and operating parameters are much greater than before due to the deregulated power supply markets and the increased number of independent power producers. Consequently, the resource development strategies determined under particular series of base assumptions and constraints may not be sufficient to guarantee a sustained competitive advantage to the utility

Systems. Utility Function model and Tradeoff/Risk analysis are two most commonly used decision analysis methods in the electric power industry for multi-attribute planning in the presence of uncertainties [1]. In 2008, integrated resource strategy planning and demand side management is introduced [2]. In 1997, tools and methods for integrated resource planning is presented [3].

This paper presents an integrated MADM methodology that combines the attractive features of utility function model and tradeoff/risk analysis and offers a structured, enhanced decision approach for handling multi-attribute planning under uncertainty. Conceptually, the proposed Decision methodology is within the framework of tradeoff/risk analysis but it introduces a novel multi-dimensional numerical knee-set searching algorithm based on the measure of composite distance, a special form of utility function model. Section 2 summarizes the basic concepts of probabilistic evaluation approach and risk evaluation approach for multi-attribute decision making under uncertainty. Section 3 introduces the integrated MADM framework for decision making under uncertainty. In Section 4, a sample case study is provided concerning with the optimal design of grid-linked renewable energy systems. Concluding remarks are given in Section 5.

Multi-attribute Planning under Uncertainty

Probabilistic Evaluation Approach: As for decision analysis under uncertainty, the utility function method is often used in conjunction with the decision tree modeling approach to provide a graphical interpretation of alternative planning strategies, decision variables and

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uncertainty factors. This decision process is usually termed as probabilistic evaluation approach by which the best solution is determined based on the expected performance of respective planning strategy under various future conditions, i.e., the expect value of composite utility.

In Decision Tree Structure, Decision nodes marked rectangles fork into branches representing resource options. Chance nodes marked as circles fork into branches representing uncertainties. In the decision tree model, uncertainty is usually addressed with the use of discrete probability estimates for the occurrence of different conditions. The sum of probabilities on branches radiating from a chance node must be equal to 1.0. Each of the terminal branches of a tree terminates at the end point marking a unique scenario, i.e., a particular combination of options and uncertainty factors that can be traced throughout the tree. In other words, a particular scenario is a complete path between the tree root and a terminal node.

For each scenario, a scalar value can be calculated by the utility function model. This would provide an overall performance index, named as composite utility or composite distance, for that scenario taking into account the contributions from different attributes. The likelihood of each scenario is determined by multiplying the probability of uncertainty for each branch tracking back from the end point corresponding to that scenario toward the decision node at the beginning of the tree.

The expected utility value associated with each planning strategy can then be determined as the sum of utility multiplied by the likelihood for each scenario relevant to that planning strategy as below.

$$U(x) = \sum_{k=1}^{m} p_k U_K(x) = \sum_{k=1}^{m} p_k \sum_{i=1}^{n} w_i . U_{Ki}(x_{ki}) \qquad (1)$$

Where U(x) is the expected utility value for each planning strategy or design alternative, U_k (x) is the composite utility for scenario k characterized by the vector of attributes x = [x_{kl} ,..., x_{kn}], p_k is the corresponding probability, U_{ki} (x) is the single utility function with respect to the ith attribute, w_i is an appropriate weighting parameter for the ith attribute, representing its relative importance in comparison to other attributes and satisfying $\sum w_i = 1$.

Finally, the planning strategy or design alternative with the optimal (maximal or minimal as appropriate) expected value is selected as the best solution.

Risk Evaluation Approach: One popular risk evaluation approach for strategic resource planning is termed as tradeoff/risk analysis. This method does not pretend to find a unique "optimal" plan, rather it is an organized approach of evaluating relationships between attributes and uncertainties and allows the identification of robust plans that are acceptable (close to optimal) under a wide range of future conditions. The tradeoff/risk analysis consists of four main steps as described below [2, 3]:

Step 1: Formulate the problem properly, in terms of options, uncertainties and attributes.

Step 2: Develop a decision database by computing attributes for a larger number of scenarios.

Step 3: Use the tradeoff concept to identify the "decision set" – the set of plans left after all inferior plans have been rejected.

Step 4: Analyze the plans in the decision set to eliminate more plans and support the development of a final strategy.

Problem Statement: The problem statement for MADM analysis under uncertainty generally involves identifying sets of options, uncertainties and attributes and creating range of scenarios to be examined.

Creation Decision Database: The decision database contains the measured attributes for each individual scenario, both quantitative and qualitative, which are calculated using analytical planning models or determined with appropriate subjective judgments.

Identification of Non-Dominated Plans: Let x_i (P_1) and x_i (P_2) be the values of the ith attribute for two plans P_1 and P_2 included in the decision database, where each plan is characterized by the vector of attributes x = [x_1 ,... , x_n]. If the objective is to minimize each attribute of the plan, then we can say that plan P_1 dominates (is better than) plan P_2 if $x_i(P_1)$ is less than x_i (P_2) for every i Є n. More precisely,

- Conditional Strict Dominance: Plan P_1 strictly dominates plan P_2, conditional on a specific future, if x_i (P_1) is better (less) than x_i (P_2) for all attributes.
- Conditional Significant Dominance: Plan P_1 significantly dominates plan P_2, conditional on a specific future, if at least one attribute x_i (P_2) is "much worse" than $x_i(P_1)$ and if no other attribute x_j (P_2) is "significantly better" than x_j (P_1).

A set of tolerance levels or significant parameters need to be appropriately selected by the utility planner which define what is meant by the term "much worse" or the term " significant better". These tolerance levels are selected independently for each attribute. For example, with attributes "total cost" and "loss of load probability (LOLP)", a planner might specify that a plan costing one.

Million dollars more than another is much worse, but that a plan costing $100,000 more than another is not significantly better. Similarly, if the difference in LOLP between two plans is greater than 2 days/year one plan is much worse than the other, while if the difference is less than 0.5 days/year, two plans can be thought equivalent relative to the performance measure LOLP.

Tradeoff Curve and Knee Set:

- Tradeoff Curve: Set of plans that are not strictly dominated by any other plan conditional on a particular future.
- Knee Set is set of plans that are not significantly dominated by any other plan conditional on a particular future. It is also termed as conditional decision set.

Decision Set Analysis: If uncertainties are modeled as unknown but bounded variables without probability assignments, then the global decision set is the set of plans that are left after all inferior plans have been eliminated.

To be more clear, plan P1 remains in the global decision set only if there is no other plan which dominates plan P1 (strictly or significantly as appropriate) for all possible futures. Finding the global decision set is obviously much harder than finding all the conditional decision sets. As a Practical matter, the global decision set can be determined approximately by the union of the conditional decision sets.

Decision set analysis supports the final strategy of resource development by identifying robust plans, robust and inferior options. In tradeoff/risk analysis, the robustness of a plan is measured in terms of the frequency with which it appears on the global decision set. In other words, the number of supporting futures determines the final ranking of alternative planning strategies. A plan that is 100% robust is a plan that is in the conditional decision set of knee set for all futures. Robust and inferior options are the discrete option values that are nearly always (robust) or rarely (inferior) in the decision set.

In the case when no plan is completely robust, i.e., there is no any single plan that is optimal or nearly so for all possible futures, hedging to reduce the risk must be applied. This is usually the real situation in electric utility planning due to conflicting objectives and diverse future forecasts. One practical and effective risk-mitigating approach is to reassemble the identified robust resource options into new plans that may be expected to perform better or more robust than any original plans.

Integrated MADM Methodologies: Another major study task of this paper is to develop an integrated MADM methodology, which would combine the attractive features of utility function model and tradeoff/risk analysis and offer a structured and enhanced decision framework for handling multi-attribute planning under uncertainty. The main motivations of developing an integrated decision methodology are as follows.

- Both utility function and tradeoff/risk methods have been widely used in the electric utility industry, but they differ from each other in the philosophy of decision criteria and the interpretations of decision process. It would be desirable if the final decision is supported by both decision methods as a consistent check, and it would be better to consider the information provided from each method as complementary views of the same problem, rather than regard them as competing contradictory attitudes of the planners.
- It is essentially important in strategic resource planning to identify a range of acceptable plans with the given attributes. In the tradeoff/risk analysis, this is determined by searching for non-dominated plans based on some specified tolerance parameters.

As with the tradeoff/risk analysis method, the proposed MADM framework can also be described by the following main steps.

- Formulating the decision problem properly
- Creating a reliable decision database
- Identifying decision sets after eliminating all inferior plans.
- Analyzing the decision sets to support the final resource strategy.

However, the proposed MADM framework differs from the traditional tradeoff/risk analysis approach in the following two important aspects:

- It provides a novel multi-dimensional numerical knee-set searching algorithm based on the measure of composite distance, a special form of utility function model, together with statistical background for the selection of appropriate tolerance level.
- It provides a decision making platform through which the competing resource alternatives can be evaluated either based on the rule of probability (i.e., probabilistic evaluation approach or expected performance) or in a risk aversion perspective (i.e., risk evaluation approach or robustness performance).

Multi-Dimensional Knee-Set Searching Algorithm: Knee-Set Searching algorithm steps are as follow:

- Define the tradeoff region after eliminating all inferior plans due to unacceptable performance of one or more attributes.
- Define the MADM model as in (1),

$$U_d(x) = \sum_{k=1}^{n} w_i \left| \frac{x_i - x_i^*}{x^r} \right| = \sum_{i=1}^{n} w_i r_i \qquad (2)$$

Where, U_d (x) is the composite distance for a particular plan measured from the ideal solution $x^* = \left[x_1^*, x_2^*, ..., x_n^*\right]$, x_i and r_i are the measured and normalized values for the ith attribute ,x_i^r is the range of the ith attribute values with x_i^* as the optimal, w_i is an appropriate weighting parameter for the ith attribute.

- Compute the value of composite distance, both the point estimate and the likely range estimate, for each feasible plan.
- Identify the best plan for which the value of composite distance is minimal, $U_{d,min}$.
- Determine the knee set, conditional on the specified future, which contains all data points satisfying.

$$U_d - \lambda_{\alpha/2}\sigma_d <= U_{d,\min} + \lambda_{\alpha/2}\sigma_{d,\min} \qquad (3)$$

Where, $\lambda_{d/2}$ is the standard deviation of normal distribution with a desired confidence interval, say 90% or 95%, σ_d and $\sigma_{d,min}$,min are the estimated errors of composite distances corresponding to the plan being examined and the best plan identified in step 4.

Hybrid MADM Decision Methodology: Hybrid decision methodology would be very helpful, as a consistent check, in support of important resource investment decisions. This dissertation suggests applying the probabilistic evaluation approach in parallel with the risk evaluation approach on the common decision database, aiming at identifying a desirable plan or plans that are acceptable not only based on the rules of probability but from the risk aversion perspective. As we discussed earlier, the risk evaluation approach will determine a set of acceptable plans based on the measure of robustness while the probabilistic evaluation approach will determine a set of acceptable plans based on the measure of expected performance. In the most desirable situation, the DM would be satisfied with one specific plan as the best solution from among the intersection of the acceptable plans recommended independently by two decision approaches as. In the case when one method is favored over the other, the hybrid decision analysis may still be useful to make more precise discriminations among competing alternatives.

Sample Study: Design of Grid-Linked Renewable Energy Systems: In this sample study, we reformulate the decision problem with only four futures selected for uncertainty modeling. These selected futures, as shown in Table (1), share the base case assumptions in wind speed, load growth, and economic factors, but differ with each other in the level of solar insolation and PV efficiency.

Decision Analysis and Interpretations: The main results of performing MADM analysis with the proposed decision methodology for the reformulated decision problem will be presented. The discussion will focus on the determination of tradeoff region, identification of conditional and global decision sets, and decision set analysis.

Determination of Tradeoff Region: Assume a group of feasible plans which each feasible plan is characterized by four design variables, i.e., wind area (m2), solar area (m2), battery capacity (kWh) and substation capacity (kW), along with three decision attributes, i.e., cost of energy production ($/kWh), expected energy unserved (%), and SO2 emissions (kg/year). These feasible plans are determined after eliminating all inferior plans due to unacceptable performance of one or more attributes. At this prescreening stage, all plans with the cost of energy production higher than 0.15 $/kWh and/or with the EENS index greater than 5% are rejected.

Table 1: Description of Selected Futures

Future	Solar Insolation (p.u.)	PV Efficiency (%)	Grid Energy Charge ($/kWh)	PV Cost ($/m^2)	Wind Speed (p.u.)	Interest Rate (%)	
A	0.9	12	0.08	450	1.0	12	
B	1.1	12	0.08	450	1.0	12	
C	0.9	17	0.08	450	1.0	12	
D	1.1	17	0.08	450	1.0	12	0

Table 2: Top 10 Acceptable Plans for Each Future

	Wind Area (m^2)	Solar Area (m2)	Sub. Rate (Kw)	Batter Rate (kWh)	Cost ($/kWh)	EENS (%)	SO2 (kg/yr)	RANK
Future A	450000	0	500	500	0.1269	2.4406	5519	1
	45000	0	600	500	0.1269	0.4941	5702	2
	50000	0	500	500	0.1316	2.0025	5186	3
	50000	0	600	500	0.1340	0.2680	5349	4
	45000	0	500	1000	0.1295	2.4373	5508	5
	30000	5000	500	500	0.1309	1.8062	5454	6
	45000	0	600	1000	0.1319	0.4904	5691	7
	55000	0	500	500	0.1364	1.6408	4867	8
	50000	0	500	1000	0.1341	1.9834	5168	9
	35000	5000	500	500	0.1356	1.5124	5105	10
Future B	30000	5000	500	500	0.1290	1.6760	5208	1
	35000	5000	500	500	0.1338	1.4046	4866	2
	30000	5000	600	500	0.1319	0.5710	5312	3
	30000	5000	500	1000	0.1316	1.6677	5187	4
	50000	0	500	500	0.1316	2.0025	5186	5
	50000	0	600	500	0.1340	0.2680	5349	6
	35000	5000	600	500	0.1367	0.3932	4961	7
	40000	5000	500	500	0.1387	1.1760	4536	8
	35000	5000	500	1000	0.1364	1.4046	4840	9
	30000	5000	600	1000	0.1345	0.5710	5290	10
Future C	30000	5000	500	500	0.1257	1.5746	5004	1
	25000	5000	500	500	0.1227	1.8680	5343	2
	25000	5000	600	500	0.1256	0.6968	5453	3
	25000	5000	500	1000	0.1253	1.8614	5323	4
	35000	5000	500	500	0.1324	1.3248	4672	5
	30000	5000	600	500	0.1304	0.5117	5104	6
	35000	5000	500	1000	0.1349	1.3246	4368	7
	30000	5000	500	1000	0.1301	1.5752	4978	8
	35000	5000	400	500	0.1308	4.2791	4395	9
Future D	20000	5000	500	500	0.1154	1.9979	5359	1
	25000	5000	500	500	0.1204	1.7129	5028	2
	20000	5000	600	500	0.1184	0.7859	5473	3
	30000	5000	500	500	0.1253	1.4362	4707	4
	25000	5000	600	500	0.1233	0.6008	5133	5
	25000	5000	600	1000	0.1228	1.7116	4994	6
	30000	5000	400	500	0.1236	4.4925	4421	7
	30000	5000	500	1000	0.1278	1.4335	4664	8
	30000	5000	600	500	0.1283	0.4471	4800	9
	25000	5000	600	1000	0.1258	0.6008	5098	10

Thus, the set of feasible plans for each specified future condition constitute the tradeoff region within which the compromise between conflicting attributes can be achieved with the use of AHP based ratio-questioning weighting-selection method and then the MADM model as in (2) can be established.

Identification of Decision Set: The value of composite distance is calculated for every plan contained by the tradeoff region using Equation (2). In this sample study, the errors due to inconsistent priority judgments are assumed to be 10% of the expected values and the errors resulting from inaccurate attribute measurements are assumed up to 5% of the range of attribute values. Then, Equation (3) is applied to identify the decision set, conditional on the specified future, by searching for the plans which may overlap with the minimum distance solution under 90% confidence interval. Finally, the global decision set can be approximately determined as the union of conditional Table 2 lists the top 10 acceptable plans for each future along with the preference ranking determined by the point estimate of composite distance.

Table 3: Summary of Global Decision Set

					Preference Ranking in Supporting Futures			
PLAN	Wind Area (m^2)	Solar Area (m2)	Sub. Rate (Kw)	Batter Rate (kWh)	A	B	C	D
G1	25000	5000	500	500			2	2
G2	25000	5000	600	500			3	5
G3	30000	5000	500	500	6	1	1	4
G4	30000	5000	500	1000	14	4	8	8
G5	30000	5000	600	500	11	3	6	9
G6	35000	5000	500	500	10	2	5	11
G7	35000	5000	500	1000	20	9	7	
G8	35000	5000	600	500	18	7		
G9	40000	5000	500	500	19	8		
G10	50000	0	500	500	3	5		
G11	50000	0	500	1000	9	14		
G12	55000	0	500	500	8	11		
G13	50000	0	600	500	4	6		

For future C, only eight plans have been found overlapping with the minimum distance solution at the given error size, therefore totally nine plans are listed in the Table. Based on Table (2), the main contributors to the optimal energy mix corresponding to future A are utility supply and wind technology. The solar resource option is only recommended by 2 out of 10 high ranked acceptable plans. On the contrary, the contribution from solar resource becomes significant in future D mainly due to the increased PV efficiency. It can also be seen that the desired penetration level of wind technology is much lower for future D as compared to the size recommended in future A. Future B and future C may represent two intermediate situations. It is apparent that, by comparing future A with future C and comparing future B with future D, increasing PV efficiency would be very beneficial to the overall performance of HSWPS in terms of all of three design objectives.

Decision Set Analysis: Table (3) gives the relevant information about the global decision set. Only the plans supported by at least two futures are listed in the table, (G1 through G13). The preference ranking of these plans in the supporting future is also provided. For example, excellent performance can be expected for plan G2 in two futures, C and D, and in both futures this plan is ranked at the second place with reference to the minimum distance solution. However, the plan G2 is not included in the decision sets associated with future A and future B. The analysis of the global decision set may conclude the following observations from which the "optimal" design strategy of HSWPS can be decided.

- Four robust plans, G3 through G6, are identified from the global decision set. These plans are acceptable for all considered futures and thus will be recommended as the candidate alternatives for the final decision making.
- All of the identified robust plans involve four energy sources indicating the complementary characteristics of these resource options in the routine system operations.
- These candidate plans reflect a conservative design attitude in utilizing wind and solar technologies and emphasize the importance of adequate storage capacity and grid supply.
- As for the best strategy, plan G3 may be regarded as more attractive than others in view of its preference ranking.
- Among other three candidate alternatives, plan G6 seems to be superior to plan G4 and plan G5 because the ranking of G6 is higher than G4 and G5 under majority (3 out of 4) of supporting futures.

More precise discriminations among candidate design alternatives can be investigated using probabilistic analysis models. The probabilistic evaluation approach will determine the expected performance for each design strategy considering the influence of various uncertainty factors. Now let us continue the above HSWPS example and assuming uncertainties are modeled with discrete probability distributions. Since probability distribution assignment is really a subjective matter, therefore, instead of giving a single set of values, it would be a good idea for the probabilistic analysis to be conducted in a manner

Table 4: Expected Performance of Robust Plans

Plan	Base Case	Case-1	Case-2	Case-3	Case-4
G3	0.3954	0.4029	0.3863	0.3896	0.4026
G4	0.4661	0.4718	0.4573	0.4709	0.4641
G5	0.4588	0.4626	0.4491	0.4630	0.4605
G6	0.4595	0.4626	0.4488	0.4634	0.4632

by investigating the solution mapping space for a range of probability distributions [6]. In this illustrative example, we will examine the expected performance of robust plans under five specified probability distributions. The base case assumes an equal chance, i.e., 0.25 to each future condition, while in other four cases, Cases-1 through Case-4, one future is assumed twice more likely to occur than other three futures. For example, in Case-1, a probability value 0.40 is allocated to future A and other three futures are assigned a value of 0.20 each. Table (4) shows the results of probabilistic analysis.

From Table(4), it is apparent that plan G3 is more attractive than other candidate alternatives while plan G4 seems not competitive to other in the selection of a final design strategy, in view of their consistent performance ranking under assumed likelihood of occurrence of different futures. On the other hand, the preference order between plan G5 and plan G6 may change under different future realizations.

CONCLUSION

An integrated MADM framework has been introduced for dealing with multi-attribute planning under uncertainty.

- It is within the framework of tradeoff/risk analysis but introduces a novel modeling approach for multi-dimensional tradeoff surface based on the measure of composite distance, a special form of additive utility function model.
- It provides statistical background for the selection of appropriate tolerance levels with which a range of acceptable plans can be determined for each specified future condition.
- It can determine for each specific future condition a best solution or the optimal plan and relative ranking information for the identified acceptable alternatives.
- It allows the DM to analyze the decision sets for the choice of best resource strategy based on the rule of probability.

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