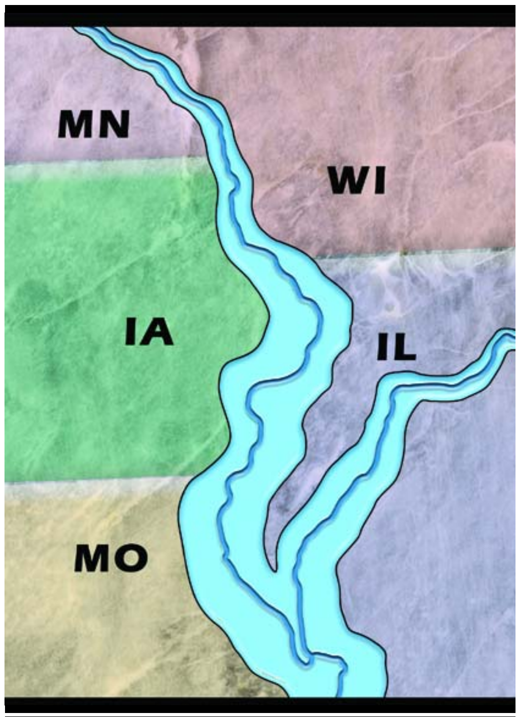
UPPER MISSISSIPPI RIVER COMPREHENSIVE PLAN



APPENDIX I

RISK INFORMED DECISION FRAMEWORK (RIDF)

Prepared by the
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UPPER MISSISSIPPI RIVER COMPREHENSIVE PLAN

APPENDIX I
R ISK INFORMED DECISION FRAMEWORK

I. OVERVIEW

To complete alternative plan evaluation, the Comprehensive Plan obtained assistance from the Corps of Engineers Engineer Research and Development Center (ERDC), located in Vicksburg, MS, in applying the new Risk Informed Decision Framework (RIDF) methodology that draws from current practice in the fields of multi-criteria decision analysis (MCDA) and risk and uncertainty analysis.

Plan H, with Plan D very close behind, and to a lesser extent Plan M, emerged as the high-scoring alternative plan using the RIDF methodology.

II. RISK INFORMED DECISION FRAMEWORK

The attached report titled "Risk Informed Decision Framework for the Upper Mississippi River Comprehensive Plan (UMRCP)" was prepared by Barry Payne and Burton Suedel of the Engineer Research and Development Center.

Risk Informed Decision Framework for the Upper Mississippi River Comprehensive Plan (UMRCP)

by

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19 November 2007

Engineer Research and Development Center
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Vicksburg, MS

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Executive Summary

This document outlines a comprehensive Risk-Informed Decision Framework (RIDF) for the Upper Mississippi River Comprehensive Plan (UMRCP) that draws from current practice in the fields of multi-criteria decision analysis (MCDA) and risk and uncertainty analysis. The RIDF is solidly grounded in and follows the 6-step Corps planning process. Where necessary, this RIDF augments the planning process by incorporating specific techniques and methods from risk analysis and MCDA.

By capturing information about attitudes and values of decision-makers and stakeholders in terms of performance metrics, and their weights RIDF facilitates communication in decision-making. Using these metrics and weights, the techniques comprising MCDA are used to derive quantitative scores for each plan under consideration. The scores represent the relative degree to which a plan satisfies the interests, values, and objectives germane to the decision.

Given the difficulty associated with accurately forecasting the future, decisions that naïvely assume certainty may be different and suboptimal compared to choices that consider uncertainty. The RIDF includes approaches for characterizing uncertainty in risk estimates and metrics and incorporating estimates of uncertainty into the quantitative scores and ranks developed for alternative plans.

Optimal decisions are affected by people's judgments concerning both probabilities and weights. Sensitivity analysis was performed within the RIDF to give decision-makers and stakeholders a tangible understanding of the relative importance of the metrics and the robustness of the ranking of alternatives in terms of their cumulative scores. In this way, the quantitative techniques within the RIDF can be used to identify the needs for follow-on studies and to facilitate communication and negotiation among the parties to a decision.

Introduction and Background

The Flood of 1993 provided a vivid demonstration of the vulnerabilities of the existing flood control systems on the Upper Mississippi River System. Flood damages continue to be incurred throughout the Upper Mississippi River System. The primary purpose of this effort was the development of an integrated strategy and implementation plan for flood damage reduction on the Upper Mississippi River System. It is also intended to address, as applicable, other components of floodplain management, including: continued maintenance and improvement of the navigation project; improved management of nutrients and sediments; environmental stewardship; and recreational opportunities. The goal of UMRCP is to recommend a comprehensive plan for systemic flood reduction and associated environmental sustainability. To develop a holistic approach to the water resource needs of the area, the risks to people, cultural heritage, the natural environment, and the economy must be considered along with construction and operations and maintenance costs to arrive at a balanced solution. To improve clarity, the following two definitions are provided.

Metric: A parameter for measuring the performance of objectives.

Plan: Any detailed scheme, program, or method worked out beforehand to accomplish an objective. Plans emerge from the plan formulation process.

The purpose of this document is to provide a technical description of the approach used to evaluate an array of alternative plans and recognize the best available plans. The first section of the document provides context for the project and the second section describes the framework. Our objective is to describe the RIDF approach and results in manner generally accessible to a broader audience familiar with Corps planning and risk and decision analysis.

Risk-Informed Decision Framework

We used a risk-informed planning process that identifies and incorporates the uncertainties that challenge our decisions and we will communicate those uncertainties to the public, stakeholder groups and decision-makers. Traditional planning methodologies are no longer enough. Changing national values regarding national security, ecosystem restoration, and regional economic development require consideration of objectives beyond national economic development. Emerging approaches to planning require the careful integration of science and social values. Risk analysis and multi-criteria decision analysis (MCDA) are evolving paradigms that can help us address this broader suite of interests. Neither traditional planning nor risk analysis, alone, is sufficient to meet the present day needs of society. The Corps proposes an amalgam of the two, called risk-informed planning. Our goal is to formulate and evaluate using the risk-informed planning.

We use risk-informed planning to:

1) Account for the major uncertainties in the planning environment that could affect the performance of plans in the future.
2) Identify, acknowledge and, when possible, fill data gaps that, if filled, could influence decisions;
3) Inform decision makers and stakeholders about the planning team's confidence level in the evidence upon which planning decisions are based; and,
4) Identify, assess, manage and communicate risks to life, health, property, environment and finances associated with problems or their planned solutions.

Evolution of Multi-Criteria Decision Analysis (MCDA) in Planning Within the US Army Corps of Engineers

The *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (also known as Principles and Guidelines or P&G) and Engineering Regulation (ER) 105-2-100, *Guidance for Conducting Civil Works Planning Studies* sets out a six-step planning process:

1. Specify problems and opportunities;

2. Inventory, forecast and analyze conditions relevant to the identified problems and opportunities;
3. Formulate alternative plans;
4. Evaluate the effects of the alternative plans;
5. Compare alternative plans;
6. Recommend a plan from the compared alternatives.

Since publication of the P&G in 1983, U.S. Army Corps of Engineers (USACE) policies have driven studies to use, essentially, a single planning objective and single measure approach to decision-making where a decision is based on a comparison of alternatives using economic factors. Planners have also been confronted with the challenge to provide for integrated systems that serve multiple objectives (e.g., a coastal system that provides for flood and storm damage reduction, navigation, and ecosystem restoration). Further, past investigations have insufficiently examined public safety implications, in particular, related to humanitarian, economic, and environmental crises resulting from rare and catastrophic events.

Cost and net National Economic Development (NED) benefits have been dominant factors used in selecting among different project alternatives in planning studies. In implementing NED-based benefit-cost evaluations, a complex analysis is performed for each alternative to determine economic benefits and costs as well as other non-dollar factors (environmental quality, safety, etc.). The alternative with the highest net NED benefit is usually recommended for Congressional authorization.

In response to a USACE request for a review of P&G planning procedures, the National Research Council (1999) provided recommendations for streamlining planning processes, revising P&G guidelines, analyzing cost-sharing requirements and estimating the effects of risk and uncertainty integration in the planning process. Implementation guidance of the Environmental Operating Principles (EOP) (htttp://www.hq.usace.army.mil/cepa/envprinciples.htm) within USACE civil works planning directs that projects adhere to a concept of environmental sustainability that is defined as "a synergistic process whereby environmental and economic considerations are effectively balanced through the life of project planning, design, construction, operation and maintenance to improve the quality of life for present and future generations" (USACE 2003a, p. 5). While adhering to the overall P&G methodology, USACE (2003b) advises project delivery teams to formulate acceptable, combined economic development/ecosystem restoration alternatives through use of multi-criteria/trade-off methods.

Over the last several years, the Corps has been developing approaches and guidance for implementing multi-criteria decision analysis (MCDA) approaches for planning (Yoe, 2002; Linkov et al. 2004; Kiker et. al. 2005). This approach utilizes a comprehensive decision analytic framework that considers a broad array of objectives and criteria/metrics, including those associated with ecosystem restoration (Males, 2002). Guidance contained in *Trade-Off Analysis Planning and Procedures Guidebook (2002)* lays out a multi-criterion decision analytic approach for comparing and deciding between alternative plans and relates the P&G six-step planning process described above to a multi-criteria analytic approach, as depicted in Figure 1.

UMRCP applies risk and decision analysis within the RIDF in a manner that explicitly considers the risks and uncertainties associated with planning, alternative evaluation, and decision-making. The approach draws from the fields of risk/uncertainty analysis and MCDA that is well-suited to the complex problem presented by UMRCP. The proposed approach enhances communication and collaboration to help achieve consensus about how various objectives and associated metrics should affect decisions, better delineate risks and uncertainties, and provide a systematic process for incorporating both qualitative and quantitative inputs to inform difficult decisions. The challenge is to select and implement an analytical approach that best serves the Corps' needs and provides outputs that can be incorporated into existing decision-making processes. In addition to serving the needs of Corps planning, this decision framework provides structure and tools for interacting and communicating with partners, stakeholders, and the public about planning and risk

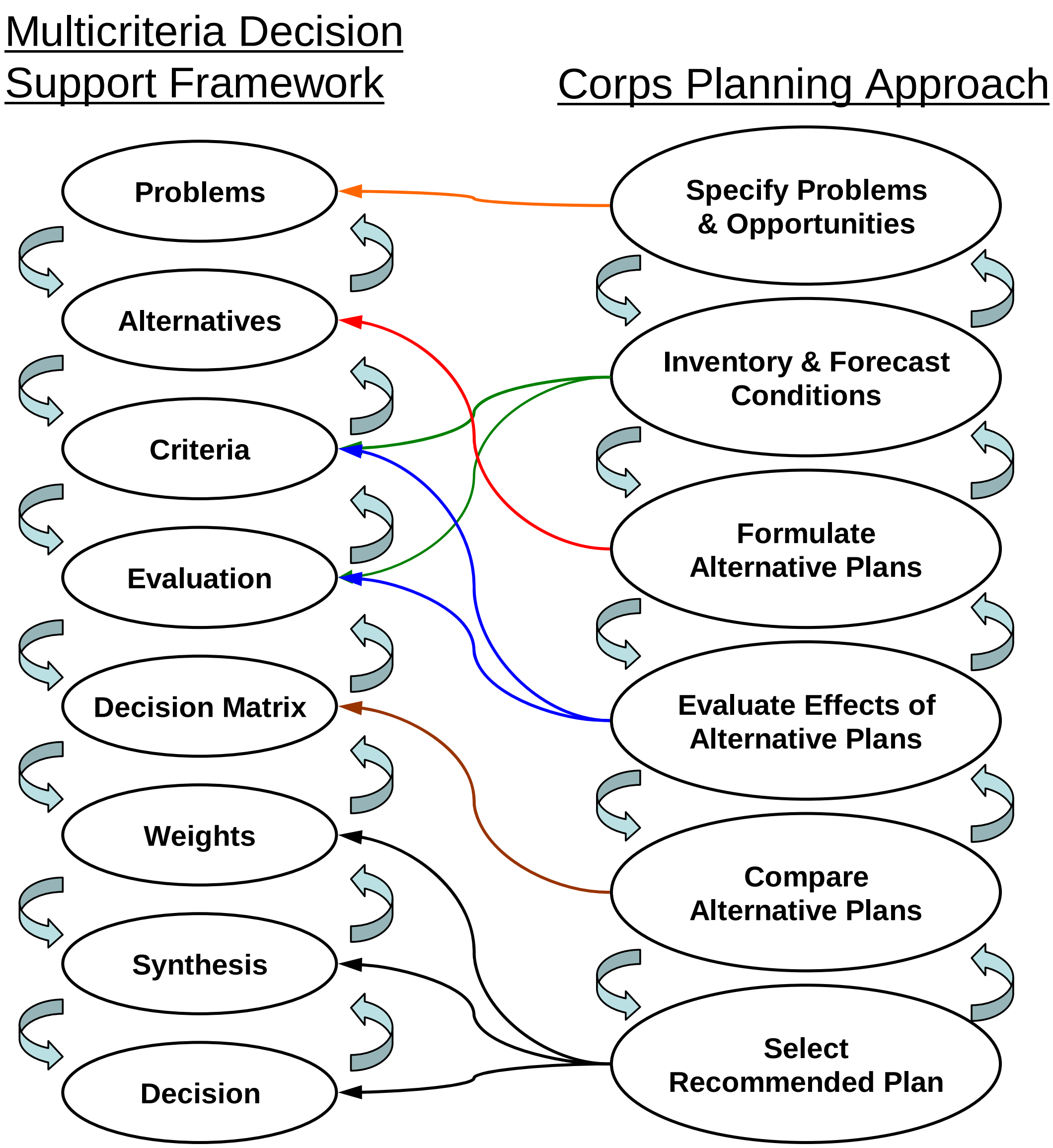

Figure 1. Relation of planning process to multi-criteria decision support framework (adapted from Yoe, 2002). The steps on the right show the current planning process practiced in the Corps. The steps in the middle show those that are generally a part of standard MCDA techniques. The use of example modeling and decision tools within the framework is shown on the left.

How the Integrated P&G and MCDA Approach was used by UMRCP Team and Stakeholders

Making effective and credible flood damage reduction planning decisions requires an explicit structure for jointly considering the positive/negative impacts and risks, along with associated uncertainties, relevant to the selection of alternative plans. Integrating this heterogeneous and uncertain information demands a systematic and understandable framework to organize complex and often limited technical information and expert judgment.

Having the right combination of ***people*** is the first essential element in the decision process (Figure 2). The activity and involvement levels of three basic groups of people (decision makers, scientists and engineers, and stakeholders) are symbolized in Figure 2 by dark lines for direct involvement and dotted lines for less direct involvement. While the actual membership and function of these three groups may overlap or vary, the roles of each are essential in maximizing the utility of human input into the decision process. Each group has its own way of viewing the world, its own method of envisioning solutions, and its own societal responsibility. Policy- and decision-makers spend most of their effort defining the restoration planning context and the overall constraints on the decision. In addition, they may have responsibility for final plan selection and implementation. Stakeholders may provide input in defining the problem, but they contribute the most input in helping formulate performance metrics and making value judgments for weighting the various metrics. Depending on the problem and restoration context, stakeholders may have some responsibility in ranking and selecting the final option. Scientists and engineers have the most focused role in that they provide the measurements for metrics that quantify the degree to which the various alternatives satisfy the objectives of the project; while they may take a secondary role as stakeholders or decision-makers, their primary role is to provide the technical input necessary to inform the decision process.

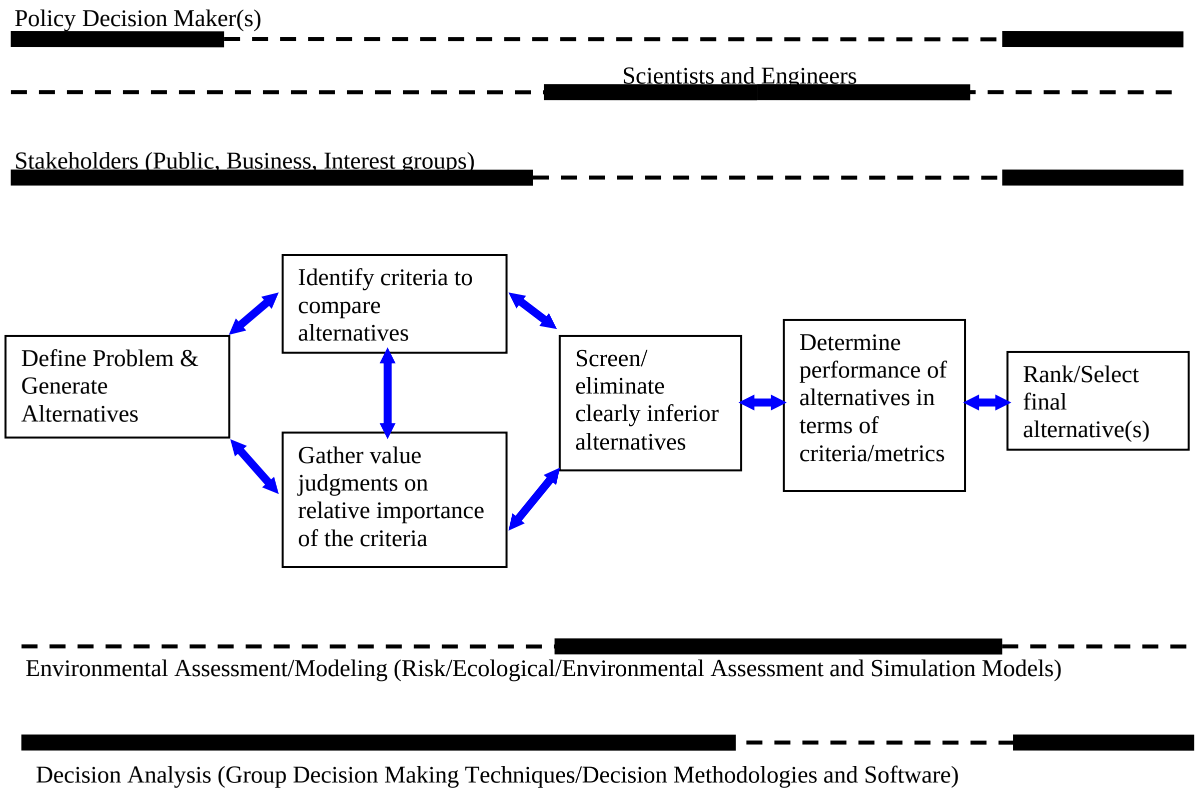

Figure 2: Proposed decision process (adapted from Linkov et al. 2004 and Kiker et al. 2005). Dark lines indicate direct involvement / applicability and dotted lines indicate less direct involvement / applicability.

To address the future challenges, the UMRCP is being coordinated with other planning efforts through a continuous exchange of ideas and information. The UMRCP plan is being coordinated via public involvement through a series of workshops, public scoping meetings, and stakeholder forums. These other planning efforts and programs involve Federal representatives, State representatives, non-governmental organizations, and the UMRCP Collaboration Team (CT). The CT have significant responsibilities for or interest in various aspects of floodplain management, particularly flood damage reduction, economic development, and natural resources.

Another way of capturing the public interests is to organize comments within the P&G system of accounts in which effects are categorized with respect to National Economic Development (NED), Regional Economic Development (RED), Environmental Quality (EQ), and Other Social Effects (OSE). This system of accounts is considered in more detail in Section 2.2.2. Engagement with UMRCP stakeholders will continue and will provide further input on problems, solutions, and values.

The ***process*** depicted in Figure 2 is composed of two major elements: (i) generating alternative restoration scenarios, performance metrics, and value judgments and (ii) ranking the alternatives by applying value weights. The process generates and defines choices, performance levels, and preferences. The process also methodically screens non-feasible alternatives by first applying screening mechanisms (*e.g.*, excessive cost, performance below minimal levels or unacceptable social consequences) and then evaluating, in detail, the remaining alternative restoration plans through the use of decision criteria/metrics that are parameterized with data from engineering models, experimental data, or expert judgment and then ranking those plans through use of MCDA techniques. MCDA separates out judgments about scaling the relative performance of alternatives using a metric from judgments about weighting those metrics (Clemen, 1995). We discuss scaling and weighting in sections 2.4 and 2.5, respectively. While it is reasonable to expect that the process may vary in specific details for different planning projects (i.e., based on project needs), the planning accomplished through use of this framework operates within an overall adaptive management structure whereby learning, accomplished through additional study and monitoring, will be used to ensure that the process is responsive to changes in decision priorities or new knowledge that can affect alternative selection or implementation strategies.

The ***tools*** used within group decision making and scientific research are essential elements of the overall decision process. The applicability of the tools is symbolized in Figure 2 by solid lines (direct involvement) and dotted lines (indirect involvement). Decision analysis tools help to generate and map technical data as well as individual judgments into organized structures that can be linked with other technical tools from risk analysis, modeling, monitoring, and cost estimations (see Section 2.1). Decision analysis tools can also provide useful graphical techniques and visualization methods to express the gathered information in understandable formats. When changes occur in the requirements or the decision process, decision analysis tools can respond efficiently to the new inputs. Figure 1 illustrates a general approach for integrating decision tools and scientific and engineering tools that are used in the UMRCP planning process.

The result of the entire process is a comprehensive, structured process for selecting the optimal alternative in any given situation, drawing from stakeholder preferences and value judgments as well as scientific modeling and risk analysis.

Implementation Framework

The overall challenge of planning and decision-making for UMRCP is that the obvious complexity and uncertainty of the problem must be condensed into a transparent, understandable, and tractable process. The complexity and uncertainty faced by decision makers is addressed using tools from the fields of Risk Analysis (RA) and MCDA to address multiple objectives, conflicting stakeholder values, both qualitative and quantitative assessments of performance, and uncertainty.

In the following sections each of the six steps of the Corps planning process is discussed in relation to RA and MCDA methods as well as to their implementation within UMRCP. Figure 1 illustrates the overall approach.

- The first step defines the boundaries of the analysis and highlights the specific questions that are answered.
- The second step includes development of performance metrics and associated uncertainties that will be used in risk-informed decision making. Links to specific engineering/resource models and tools will be established and assessed in this step. The result of Step 2 is the list of metrics that was used within the process.
- The third step in the process is the formulation of alternative measures. During this step, specific measures are formulated by the project team. Screening criteria

are applied to eliminate clearly infeasible measures prior to combining the remaining measures into alternative plans that are subjected to detailed evaluation.

- The fourth step in the process is the evaluation of formulated plans. Performance is measured in terms of pre-selected metrics from the system of accounts and comparison will be made to without project conditions. Alternatives are scored using MCDA tools.
- The fifth step uses trade-off analysis to identify and eliminate objective-dominated plans. Remaining plans are compared by combining information supplied by utility functions developed in Step 4 by technical experts with metric/criteria weights representing the value judgments of stakeholders.
- The sixth step selects a recommended plan. The plan is based on all the assembled information collected in the planning process, including all the values, weights, and metrics used to score and rank the alternatives.

Specify the Problem and Opportunities

The first step is to define the boundaries of the analysis. Defining the problem for a comprehensive plan may appear to be relatively straightforward, but it may be one of the most difficult and critical tasks. Among the boundary issues, it is important to clearly define temporal and spatial scales. For example, the most preferred alternative may vary among adjacent communities. Factoring such spatial variation into how the framework is used along the Upper Mississippi River should be considered. Similarly, the most preferred decision may vary as a function of the timeframe under consideration: a longer planning timeframe would likely lead to a preference for higher fixed costs and lower operational/maintenance costs.

The Flood of 1993 awakened renewed interest in developing a systemic approach to flood damage reduction on the Upper Mississippi River System. In authorizing this study, Congress recognized the need for a planning effort that develops a floodplain management plan that can be implemented and for which there is a Federal interest. That plan needs to address the immediate problem of reducing future flood damages, but also needs to evaluate the potential for a future, more-resources inclusive, integrated river resources management program.

The following problem statement was drafted with the above issues in mind: The people, economy, and environment of the Upper Mississippi River, as well as the Nation, are at risk from flood events as manifested by:

- Increasing risk to people and property from catastrophic flood events.
- Increasing vulnerability of riverside communities to inundation from storm induced flood damages.
- Regional economic losses from flooding to residential, public, industrial, commercial infrastructure, and agricultural assets.
- Losses to high levels of productivity and resilience of the Upper Mississippi River ecosystem due to natural conditions and storm disturbances.

Inventory and Forecast to Establish Baseline Conditions

The second step of the planning process develops an inventory and forecast of critical resources (physical, demographic, economic, and social, etc.) relevant to the problems and opportunities under consideration in the planning area. The measures being evaluated in the UMR Comprehensive Plan are intended to address both present and future risks associated with flood inundation events. Evaluating future conditions under the no action alternative plan requires making predictions about what conditions, in terms of management criteria, will exist in the future.

Parameter Uncertainties

Decision-makers and stakeholders commonly have different attitudes toward risk and uncertainty as reflected in their views about risk outcomes and the distribution of those outcomes. Decision-makers are often observed to be risk averse because they want to achieve their objectives with more certainty. For a given expected value of model outcomes, people generally prefer lower variance or uncertainty. As a result, the expected performance for flood damage reduction measures being considered by a given decision is determined by the combined effect of the expected value of the measure and the uncertainty associated with that expected value (Keeney and Raiffa 1976; Kim et al. 2003). Therefore, explicit consideration of uncertainty in management decisions can result in more prudent decisions and better expected performance than if uncertainty is disregarded.

However, it is often not practical to consider uncertainties in each and every model parameter. We must decide which parameters are the most important to the overall model's output and whether it is likely to be worthwhile gathering more information, performing a more detailed risk analysis, and refining the mathematical model to propagate the uncertainties that matter through analysis and decision-making. The RIDF for UMRCP makes use of two approaches for identifying important sources of uncertainty and incorporating that uncertainty into modeling:

- Sensitivity analysis to analyze the effect of changes in input values on the model prediction. This analysis can be used to screen and characterize the relative importance of different sources of uncertainty[1]; and,
- Uncertainty propagation[2] to calculate the uncertainties in the model outputs induced by the uncertain inputs. The Monte Carlo method is often used to approximate such model output distributions (Fishman, 1996) and propagate the input uncertainties.

Objectives

The purpose of this section is to delineate the objectives appropriate to a sound solution to the UMRCP decision problem that can be readily articulated to an array of audiences.

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[1] The simplest way to screen for important uncertain parameters is a first order analysis (Iman and Helton, 1985). Uncertainty importance is defined as a product of a normalized parameter's sensitivity and its normalized uncertainty (coefficient of variation).

[2] Because of sample error, the Monte Carlo method is only an approximation to the exact distribution of outcomes. Therefore the accuracy of the method can be improved by increasing the number of independent samples (Morgan *et al.*, 1990). Alternatively, during the Monte Carlo process, the Latin Hypercube Sampling (LHS) Method in variance reduction techniques are used to reduce the standard error of the mean (*i.e.*, the standard deviation of the sampling distribution of the mean), improving computation efficiency (Iman and Helton, 1985).

As a group, a good set of planning objectives must be collectively exhaustive. That is, nothing that really matters can be left out. However, and again with an eye to simplification, the list must be winnowed down to only the ones that really do matter. A hierarchical arrangement of objectives (e.g., a principal objective branching to a tier or two of sub objectives) is often useful for structuring a complex decision.

Each objective should be specific and succinct (Keeney and Raffia 1976). An objective must be unambiguous yet still succinctly stated, as brevity helps communication and clarifies thinking. Each objective must be amenable to measurement using one or a few metrics so that predictions can be quantified and performance ultimately can be assessed. Simultaneously, objectives must be realistically achievable and relevant. Finally, there must be concordance with practical time frames (Hobbs and Meier 2000). In other words, predictions must be possible within the planning time frame or monitoring of performance must be possible within a useful time frame.

The planning objectives for UMRCP are to:

- Minimize the threat to health and safety resulting from flooding by using structural and non-structural flood damage reduction measures;
- Reduce damages and costs associated with flooding;
- Identify opportunities to support environmental sustainability/restoration goals of the Upper Mississippi River and Illinois River floodplain as part of any systemic flood damage reduction plan;
- Seek opportunities to address, in concert with flood damage reduction measures, opportunities to include reduction of nutrient input and sedimentation into the rivers.

The objectives identified in the preceding paragraph are organized within the RIDF framework using the USACE P&G System of Accounts (Yoe and Orth 1996), which guides an evaluation of the effects of a project with respect to National Economic Development (NED), Regional Economic Development (RED), Environmental Quality

(EQ), and Other Social Effects (OSE). Establishing the system of accounts 1) shows all effects important to decision-making, 2) explicitly shows the NED effects as the basis for establishing the economic feasibility of the plan, 3) offers a rational, organized framework for presenting the results of the UMRCP analysis, and 4) provides a means for comparing plan effects. The plans' effects presented in the system of accounts relate to the plans' contributions to planning objectives. The effects of the plans are arranged such that the differences among the plans are easily discerned.

In recent history, USACE planners have been guided to select the NED plan (the one maximizing national economic development benefits) as the preferred alternative, while still meeting National Environmental Policy Act requirements. The present multi-attribute analysis of UMRCP alternative plans is broadly seeks a cost-effective plan that best meets objectives across the NED, RED, EQ, and OSE accounts. Metrics proposed in the subsequent section for evaluating project effects in UMRCP are categorized according to these four accounts.

Metrics

Metrics used to guide the UMRCP evaluation are presented in Table 1. These metrics were used to score and then rank flood damage reduction plans. In selecting this set of metrics, we strove to represent the best available information for evaluating alternatives

Table 1. UMRCP Objectives and Metrics.

Plan Performance Objectives for Risk Reduction		Metrics	(Units)	Description	Data Source
People	Reduce social effects of flooding using structural and non-structural flood damage reduction measures.	Other Social Effects (OSE): - Public Health and Safety - Transportation - Community Cohesion - Controversy	None (-5 to +5 scale)	Estimates plan effects on a variety of important social factors.	Expert opinion informed by empirical data
Economy	Reduce economic damages associated with flooding and enhance national and regional economy.	National Economic Development (NED): - Construction Costs - Annual Net Benefits - Benefit-To-Cost Ratio (BCR)	$$ (costs and benefits) none (BCR)	Estimates economic changes with respect to national output of goods and services.	Empirical data and models
		Regional Economic Development (RED): - Economic Development - Construction Costs	$$	Estimates stimulation of regional economy (e.g. income and employment).	Regional Economic Model, Inc. (REMI), customized to UMR.
Environment	Support environmental restoration and sustainability goals in the Upper Mississippi and Illinois river floodplains.	Environmental Quality (EQ): - Mitigation - Secondary Development - ER Opportunities	Acres	Estimates plan effects on environmental quality in relation to regional goals for restoration and sustainability.	Empirical Data and Expert Opinion

in the UMRCP, keeping in mind the characteristics of effective metrics (see Roy, 1985; Seager et al. 2007, Graedel and Allenby 2002, Seager and Theis 2004; Yoe 2002). Effective metrics are:

- **scientifically verifiable.** Two independent assessments would yield similar results.
- **cost-effective**. The technology required to generate data for the metrics is economically feasible and does not require an intensive deployment of labor.
- **easy to communicate to a wide audience.** The public would understand the scale and context and be able to interpret the metric with little additional explanation.
- c**hangeable by human intervention**. The metric would have a causal relationship between the state of the system and the variables that are under a decision-maker's control. Metrics that are independent of human action do not inform a management, policy-making, or design process.
- **credible**. It would be perceived by most of the stakeholders as accurately measuring what it is intended to measure.
- **scalable.** It would be directional, whether qualitative (best, good, worst) or quantitative, as appropriate.
- **relevant**. It would reflect the priorities of the public and other stakeholders and enhance the ability of managers and/or regulators to faithfully execute their stewardship responsibilities. There is no point assembling a metric no one cares about.
- **sensitive** enough to capture the minimum meaningful level of change or make the smallest distinctions that are still significant, and it would have uncertainty bounds that are easy to communicate.
- **minimally redundant** in that what it measures is not essentially reflected by another metric in the set being used.
- **transparent** such that use of the metric avoids "readily unapparent and/or known agendas."

It is important to acknowledge here that there are "conflicts" among plan results as measured by these metrics, resulting in the need to make tradeoffs. For example, a tradeoff may exist between achieving any significant benefit from a project and minimizing cost. The tradeoff concept is discussed in Step 5. As a consequence of such "conflicts", a given measure or alternative may not take clear precedence over other measures or alternatives in respect to every metric for evaluating performance. This may present a dilemma to decision-makers, who are trying to choose a single measure or plan. It is important to place development of metrics prior to the formulating plans because the "hard thinking" that goes into developing the metrics can create an improved set of measures from which to formulate plans; this in turn permits stakeholders to focus on thinking about the objectives rather than anchoring themselves to favored measures (Keeney and Raiffa 1976).

Uncertainty is clarified by delineating the magnitude of uncertainty surrounding metric value estimates. Metric estimates depend upon a mathematical model, empirical data from a study, or expert opinion. All of these sources share varying degrees of knowledge uncertainty, presumably more so for expert opinion than for models and studies. Along with indicating the basic source of metric estimates, it is necessary to explicitly state the important underlying assumptions and indicate which are highly uncertain, moderately uncertain, or highly certain. Beyond these fundamental elements, estimates of uncertainty for metric values should be quantified (e.g., in terms of the variance or range associated with the estimate). Such quantification of the level of uncertainty surrounding metric estimation must be captured and integrated in the decision analysis to make risk-informed decisions.

In the following four sections the proposed metrics for UMRCP are listed and described (Table 1).

National Economic Development (NED) Metrics:

Benefit-To-Cost-Ratio (BCR): This unit-less ratio is computed by dividing average annual NED benefits by average annual costs. A BCR increase indicates greater value for a given cost.

Annualized Net Benefits: This metric represents the average annual NED benefits minus the average annual costs, expressed in dollars. Average annual benefits are defined as the difference in average annual damages between the without project (existing condition) and with project condition. A larger positive value is better than a smaller or negative value.

Construction Cost (First Cost): The cost, in dollars, of implementing a plan. Cost estimates focused primarily on levee construction and modification. Costs for levee degradation, new levee materials, berm materials, additional levee right-of-way, acreage of seeding, acreage of clearing and stripping, crushed stone, asphalt cement concrete, and other needed items were also estimated. The most preferred plan with respect to only this metric would be the lowest cost plan. Values for this metric were transformed prior to use in the decision model (max value minus observed value) such that a high score on this metric indicated a preferred option (lower cost).

Environmental Quality (EQ) Metrics*:*

Mitigation (Acres): This metric indicates the magnitude of habitat mitigation required under each alternative. We determined the net change in levee/floodwall footprint and affected habitat acres for each plan using engineering design data and GIS. The total impacted acreage of open water, non-forested, and forested habitat for each plan was then multiplied against a generic mitigation cost per restored floodplain acre. The most preferred plan with respect to this metric would be that with the least required mitigation. Values for the metric were transformed prior to decision analysis such that a high score reflected lower mitigation requirement.

Secondary Development (Acres): This metric represents the land area that would be brought to or above the 100-year flood level by protective measures of a plan. Such acreage would become available for potential development in a manner considered to have an adverse EQ effect. Thus, the most preferred plan with respect to this metric should be that with the least amount of secondary development. Values for this metric were transformed prior to decision analysis such that a high score reflected low secondary development.

Ecosystem Restoration Opportunities (Acres): This metric represents managed ecosystem restoration areas in the drainage and levee districts, expressed in acres. A high amount of such acreage is preferred to a low amount.

Regional Economic Development (RED) Metrics:

Economic Development: This metric estimates the economic development benefit of reduced flood risks. These benefits derive from such factors as land zoning changes, increased commercial activity, reduced operating costs, more protected transportation and utilities. Economic Development is estimated using nationally-consistent projections of income, employment, and output and is expressed in dollars.

Construction Cost: Expenditures on labor and materials required to build levees and other structures stimulates the regional economy. In general, higher construction costs yield more RED benefits.

Other Social Effects (OSE) Metrics:

Each OSE metric was scored on a -5 to +5 scale, with higher scores reflecting more preferred outcomes.

Public Health and Safety: This metric estimates beneficial effects to health and safety. Thus, plans with higher values of this metrics are better at reducing risks of flood, drought, or other disaster. Sources of health and safety risks are diverse and not always direct and included factors such as disease-carrying insects, pathogens, air pollution; and disrupted food supply.

Transportation: This metric estimates beneficial effects on the transportation system. Therefore, plans scored higher for this metric if they are better at reducing potential disruption of the transportation system, and allow persons and goods to move more easily.

Controversy: For this metric, a higher score means a less controversial plan. Factors considered include landowner impact, cost, and changed flood elevation.

Community Cohesion: This metric represents the degree to which a plan avoids breaking apart, moving, or otherwise disrupting the cohesiveness of a community. Essential elements of cohesion include shared goals, physical proximity, social similarity and relationship, neighborhood conditions, and group activities.

Formulation of Alternative Plans

Plan formulation is the process of building plans that meet planning objectives and avoid planning constraints. It requires the knowledge, experience, and judgments from many professional disciplines, as well as the views of stakeholders, other agencies and non-governmental organizations (NGOs), and the public. Plan formulation capitalizes on imagination and creativity wherever it is found, across technical backgrounds and group affiliations.

Development of alternative plans incorporated the use of a Collaboration Team (see Table 2 in Results) to help ensure that diverse expertise, experience, knowledge, and stakeholder interests were represented throughout plan formulation. This team reflected the views of multiple agencies, non-governmental organizations (NGOs), and different component of public interest represented by those organizations. Fourteen plans were initially formulated – Plans A through M plus a No Action alternative. Plans B, G, and

M were represented in the MCDA reported herein by Plan M alone – the three plans were similar. Plans C, F, I (similar to J), K, and L were dropped from analysis due to insufficient data to support MCDA. Each alternative plan was refined by an iterative process until the Team was comfortable that an array of plans had been developed that were appropriate to address system-wide reduction of flood risk reduction in light of social, economic, and ecological concerns. The Plans forwarded for evaluation combined what was perceived as an optimum array of structural and nonstructural measures within each of several categorically different approaches to a system-wide flood risk reduction.

Plans "No Action," "D," "E," "H," "J," and "M" were forwarded for evaluation. Each plan is described below.

No Action

Description. The No Action plan represents the future condition without any Corps project as a result of the Comprehensive Plan. Refer to Section 2, *Future Without Project Conditions.* All other alternative plans are compared to this, the No Action plan, to determine the benefits and costs of each plan. If no action is taken, significant flooding could occur on the system.

Plan Summary

- Urban - no change to the existing level of protection which varies by location
- Agricultural – no change to the existing level of protection which varies by location
- Unprotected towns – no change to the existing level of protection which varies by location
- Other existing unprotected areas – no protection
- No mitigation required

Discussion. The No Action plan represents the future conditions without any project as a result of this study. In general, the landscape will remain generally as it exists. Significant changes will occur only in relatively localized areas.

Plan D (500-y Urban, ; 100-y Agricultural Protection)

Description. This plan involves protecting areas with existing levees/floodwalls to the 0.2 percent chance annual (500-year) level for urban areas and approximately the 100-yr level for agricultural areas (the level of protection would be left intentionally insufficient to obtain FEMA certification). Unprotected urban areas would be protected to the 0.2 percent chance annual (500-year) level. The hydraulic impacts of this alternative on flood profiles and the Lower Mississippi River would be minimized through creation of additional storage areas and/or the exclusion of some agricultural districts from the plan.

Plan Summary

- Urban - 0.2 percent chance annual (500-year) protection
- Agricultural – approximately 100-yr protection
- Unprotected towns – 0.2 percent chance annual (500-year) protection (levee encompassing only existing development)
- Other existing unprotected areas – no protection
- Mitigation of all impacts due to plan implementation

Discussion. This floodplain management plan was intentionally developed such that for existing protected areas which require a raise in protection height, the new height would be less than required to obtain Federal Emergency Management Agency (FEMA) certification as providing protection for the base, or 1 percent chance annual, flood event. This plan would minimize new floodplain development in concert with current Federal policies of not inducing floodplain development while raising the level of protection for many of the agricultural levee districts.

Plan E (500-y Urban, 50-y Agricultural Protection)

Description. This plan involves protecting areas with existing levees/floodwalls to the 0.2 percent chance annual (500-year) level for urban areas and the 50-yr level for agricultural areas. Unprotected urban areas would be protected to the 0.2 percent chance annual (500-year) level. The hydraulic impacts of this alternative on flood profiles and the Mississippi River and Tributaries (MR&T) Project, would be minimized through creation of additional storage areas and/or the exclusion of some agricultural districts from the plan.

Plan Summary

- Urban - 0.2 percent chance annual (500-year) protection
- Agricultural – 50-yr protection
- Unprotected towns – 0.2 percent chance annual (500-year) protection (levee encompassing only existing development)
- Other existing unprotected areas – no protection
- Mitigation of all impacts due to plan implementation

Discussion. As with alternative plan D, this floodplain management plan was intentionally developed such that for existing protected areas which require a raise in protection height, the new height would be less than required to obtain Federal Emergency Management Agency (FEMA) certification as providing protection for the base, or 1 percent chance annual, flood event.

Plan H (500-y Urban and Agricultural Protection)

Description. This plan involves protecting areas with existing levees/floodwalls to the 0.2 percent chance annual (500-year) level of protection. 0.2 percent chance annual (500-year) level of protection applies to urban, agriculture and unprotected communities. The hydraulic impacts of this alternative on the Lower Mississippi River would be minimized through creation of additional storage areas and/or the exclusion of some agricultural districts from the plan. This plan is identical to Plan B, with the exception of areas where the cost of the levee improvement exceeds the value of the land to be protected.

Areas that meet these criteria would be purchased in fee title and actively managed for ecosystem benefit. For the analysis at this time, it is assumed that the levees would remain in place at their current height, and the water levels within the interior of the drainage district would be actively managed for wildlife purposes and flood storage, if needed.

Plan Summary

- Urban - 0.2 percent chance annual (500-year)
- Agricultural areas – 0.2 percent chance annual (500-year), cost effective comparison of the levee improvement cost versus value of land cost
- Unprotected towns – 0.2 percent chance annual (500-year) protection (levee encompassing only existing development)
- Existing unprotected areas – no protection
- Mitigation of all impacts due to plan implementation

Discussion. For agricultural areas with existing protection, a comparison of the cost to implement the raise (construction cost estimate) to the cost to purchase the area in fee was made using an average fee cost of $6,000 per acre. The more cost effective option would then be chosen if this plan were to be implemented. As initially formulated, for agricultural districts it was either raise the level of protection to 0.2 percent chance annual or fee purchase. If this alternative plan were evaluated further, additional assessments would be done to determine whether real estate easements are required for the areas where lines of protection are not increased, and to evaluate associated ecosystem benefits.

Plan J (Floodplain Management)

Description. This alternative involves a change in floodplain management policies to restrict urban development in the 0.2 percent chance annual (500-year) floodplain, and the removal of existing flood protection systems in agricultural areas to increase floodplain connectivity. Permanent evacuation of flood prone developed areas involves the acquisition of lands by purchase, the removal of improvements, and the relocation of the population from such areas. Lands acquired in this manner could be used for recreation, ecosystem restoration, or for unprotected agriculture at the higher elevations.

Plan Summary

- Urban – 0.2 percent chance annual (500-year) protection
- Agricultural Levees – removed/no protection and buyout developed areas in agricultural levee districts
- Unprotected towns – no protection/buyout
- Unprotected agricultural– no protection
- Mitigation of all impacts due to plan implementation

Discussion. Economic resources in the floodplain will always be at risk. Traditional structural approaches to floodwater management have provided significant protection from flooding. However, there can be disadvantages to using structural approaches, including: increased risk of catastrophic flooding if structures fail or the flood damage reduction system capacity is exceeded; damage to natural resources and natural floodplain function; and increased economic damages if catastrophic flooding occurs. A second approach is to evacuate floodplains and move residents and their public and private investments to less risky areas. (Interagency Floodplain Management Review Committee, 1994).

Objectives of this alternative are to:

1. reduce the vulnerability of the nation to loss of life and property and the disruption of societal and economic resources caused by flooding;

2. sustain, restore, or enhance the natural resources, ecosystems, and other functions of the floodplain; and
3. prevent repetitive losses from flooding.

This plan evaluated the impacts of removing all agricultural levees along the Mississippi and Illinois Rivers. Existing urban levees/floodwalls are assumed to remain intact. Agricultural levee removal could result in a mixture of floodplain development. To capture this uncertainty, two bounds, or conditions, of floodplain developments were evaluated in this plan. The lower bound is that the floodplain would turn totally into an agricultural regime. The upper bound would be that the floodplain would revert back to natural ecological succession in the floodplain. If agricultural levees would be removed, then the impact to water levels on the flood plains could be within the bound created.

Plan M (500-y Urban and Agricultural Protection with No Minimization of Impacts to Lower Mississippi River Valley)

Description. This plan involves protecting areas with existing levees/floodwalls to the 0.2 percent chance annual (500-year) level of protection. 0.2 percent chance annual (500-year) level of protection applies to urban, agriculture and unprotected communities. The goal by relaxing the third design criteria, minimize impact downstream to the MR&T Project, is to allow additional systems south of St. Louis to raise their level of protection. Plan M is very similar to and represents Plans B and G, of which there are only minor variations between the three plans, Plans B, G and M. Therefore, Plans B and G were not specifically compared using the RIDF. Plan M differed in that it did not include a 10,000 acre storage area located in Monroe County, IL and allows only a single drainage and levee district south of St. Louis to provide a level of protection sufficient for a 0.2 percent chance annual (500-year) event (plan G allowed 6 districts to similarly raise levees) .

Plan Summary

- The third criteria to minimize impacts on the MR&T Project does not apply to this plan

- Urban - 0.2 percent chance annual (500-year)
- Agricultural – 0.2 percent chance annual (500-year)
- Unprotected towns – 0.2 percent chance annual (500-year) protection (levee encompassing only existing development)
- Other existing unprotected areas – no protection
- Mitigation of all impacts due to plan implementation

Discussion. Actual induced rise for Plan M at the MR&T Project is 0.3 feet for the 1 percent (100-year) flood event. This induced rise may require mitigating this rise on the MR&T Project if Plan M were to be implemented. Plan M allows only one drainage and levee district, the Bois Brule Drainage and Levee District, south of St. Louis to raise to the 0.2 percent chance annual (500-year) event level of protection. Plan M does allow the other drainage and levee districts south of St. Louis to be raised by the amount of induced water surface rise so that, in effect, the districts south of St. Louis maintain their existing level of protection.

Evaluation of Alternative Plans

The most basic of information requirements for using MCDA to evaluate plans are: i) estimates of the performance of each plan according to each metric, and ii) a weight assigned to account for relative differences in the importance of metrics.

Metric Estimation. Performance of each plan for each metric was estimated by the District Technical Team and is summarized in Table 2. It is noteworthy that the No Action plan data differ greatly from those for the other plans. By definition, the No Action plan takes a zero value for nearly all metrics.

Although the No Action plan is described in Table 2, it is not mathematically compared to the other plans using MCDA. Inclusion of the No Action plan would limit analytical ability to discriminate among the other plans (they would tend to cluster together by virtue of the fact that all differ greatly from the No Action alternative). MCDA is used herein to identify the better choices among alternatives D, E, H, J, and M to subsequently consider against taking No Action – a required baseline for USACE project analysis. The No Action plan is considered in relation to the better choice plans in order to guard against an inappropriate decision if No Action is clearly preferable.

Metric Weighting. A stakeholder weight-elicitation workshop was conducted to assign weights to each performance metric. The workshop was held on 5-6 September in St. Louis, MO at the Holiday Inn Airport Oakland Park. Burton Suedel and Barry Payne from the USACE ERDC and the UMRCP technical team members attended to answer technical questions that arose and to document the process. Group Solutions (Brett Boston and Vern Herr) facilitated the sessions and electronically elicited the weights from each of the stakeholder groups. Comments received after the workshop were positive, with an emphasis on continued involvement of the Collaboration Team of stakeholders, including Corps response to their feedback.

The main objective of the workshop was to openly engage representatives of the Collaboration Team in a series of steps leading to weighting of the performance metrics. The Collaboration Team first met in late 2002 and has been an integral component of the UMRCP effort throughout the subsequent five years. These individuals represent a diverse array of interests and organizations and include individuals from government (Federal and state) non-government organizations (NGOs) (Table 3).

Day 1 was spent with a team of Corps personnel (Corps Team, Table 4) that has been highly involved in the UMRCP effort to familiarize them with the MCDA process, answer questions, and collaboratively resolve issues surrounding metric narratives, metric estimates, and metric weighting. The same polling process was used to elicit weights for the Corps Team near the end of Day 1 as was used to elicit weights on Day 2 from the Collaboration Team representatives.

The weight elicitation workshop implemented the direct-scoring method to provide decision makers with key stakeholder group perspectives. Those perspectives were provided by having the teams rank and then weight each several (2-4) performance metrics that comprised the individual components of each of 4 “accounts” (NED, RED, EQ, and OSE) into which metrics were classified. The accounts themselves were similarly ranked and weighted. This hierarchical structure facilitated linkage of the workshop results to the USACE planning process, helped guide metric weight elicitation, and facilitated subsequent communication of results (i.e., comparisons among 4 clusters of metrics can be comprehended more readily than comparisons among a list of 12 individual metrics).

An intranet-based system was used to gather weight data from participants. Each participant was assigned to a laptop computer to rank metrics. Results were compiled real-time and shared with the group so that weights could be discussed.

Background information was provided to the Collaboration Team, including information on estimated performances of the various alternative plans (Table 2) and a synopsis of how the Corps came to use an MCDA approach to reconsider these plans (all of which had been earlier scrutinized and essentially tabled because none had a sufficiently high benefit-to-cost ratio). That prior history was well known to the Collaboration Team and was a source of concern. A brief overview was provided of how and why a risk-informed decision framework with MCDA was being used to evaluate potential projects to enhance coastal storm protection in the aftermath of hurricane Katrina. Both the Corps Team and ERDC answered questions during the introductory portion of Day 2. Then, we discussed the metric set, its importance, and clarified metric definitions as appropriate. Next a trial run was made to familiarize individuals with both the software and weighting process, resolve any confusion, and set the stage for the polling steps that would be used to support plan evaluation.

A series of “polls” were conducted. In the first of these, participants were asked to ordinal rank the 4 “system of accounts” (NED, RED, OSE, and EQ) from most to least important, where each participant was asked to "wear the hat" of their job within their organization. The results were shared and discussed briefly. Next, the Collaboration Team representatives were asked to allocate points to each metric, thus providing finer distinction of the relative importance of metrics. Allocation was done with three rules. First, no individual metric could be given more than 70 points. Second, 100 points was available for the sum total of points given to all metrics. Third, all 100 points must be used. The same process was used of first ranking and then allocating points to the individual metrics within each categorical metric. Thus, the weight of a particular metric equaled its point allocation divided by 100 (weights were scaled 0 to 1).

Results of the multi-criteria decision analysis obviously differed for the Collaboration and Corps team weightings. The results for the two teams are first presented separately and are then briefly compared in order to recognize those plans that faired well using the metric weightings of both teams.

Collaboration Team: Metric Weights and Decision Scores. Table 5 summarizes the weights elicited from the Collaboration Team for system accounts (NED, EQ, RED, and OSE), the metrics within each account, and the cumulative weight for each metric. The diversity of stakeholder opinions represented on the Collaboration Team is reflected by the high ratio of the standard deviation-to-mean of many of the metrics. For example, at the account level, the standard deviation was greater than the mean for NED, EQ, and OSE. In contrast, the team representatives were more uniform in their view of the relative importance of each of several other metrics (i.e., NED: Benefit-to-Cost Ratio, RED: Economic Development, RED: Construction Cost, and OSE Public Health). The cumulative weight of each metric represents the weighting at the account level multiplied by the weighting of each metric within a particular account. These cumulative weights sum to unity.

Figure 3 is a graphical hierarchy that shows the account-level weights, the cumulative weights of each metric and the resultant decision score for each plan. These decision scores were 0.54, 0.54, 0.52, 0.44, and 0.38 for plans M, H, D, J, and E, respectively.

The relative decision scores of the five alternative plans are graphically portrayed in Figure 4.

Table 6 summarizes the computation of each decision score and provides information on performance with respect to each metric. The score S_i under each plan represent the normalized score across plans with respect to each of the metric (i=12). This normalized score is weighted by multiplying it with the mean weight of the metric (W_i). The sum of all W_iS_i equals the decision score (which is often referred to as the additive utility). Also shown in Table 6 is the standard deviation relative to the mean for the twelve S_i values for each plan. This ratio indicates the balance of a plan with respect to performance against multiple objectives. Two of the higher scoring plans, H and D, also showed relative high balance in their performance with respect to the entire metric list; both had moderately low SD-to-mean ratios (0.411).

Figures 5 and 6 graphically portray the degree of balance in each plan's performance against the metric list. Figure 5 shows metrics only at the four account levels; Figure 6 shows individual metric contributions across all accounts. In both Figures, the relatively balance performance is evident for Plans H and D compared to the other plans. Furthermore, no single evaluation metric contributes more than about 30% of a decision score (e.g., the relative contribution of RED: Economic Development to the decision score for Plan M). For the most part, individual metrics rarely account for more than 20% of the decision score for any particular plan, and many metrics contribute much less than 10%. These results reflect the balanced appraisal of plans made possible by incorporating diverse stakeholder views into an average weight for each metric.

In Figures 5 and 6, the total absence of contribution of a particular metric to the score for a particular plan can be misinterpreted. For example, EQ: Managed Acres made no contribution to the decision score of Plan M in Figure 6. In this example, the managed acres estimated for Plan M was not zero; indeed, there were 42,000 managed acre estimated for Plan M (Table 2). However, this value of 42,000 was the lowest among the four plans and became zero *via normalization*. In comparison, the highest value for managed acres (808,000 for Plan J) is set to 1.0 by the normalization procedure. Proper inspection of Figure 5 and 6 requires an awareness of the relative normalization of scores among plans for each metric.

Table 2. Estimated performance of each plan with respect to each metric.

Account/Metric	No Action	Plan D	Plan E	Plan H	Plan J	Plan M
NED						
BCR	0	0.0563	0.0668	0.0584	0.000	0.0451
Annual Net Benefits ($*10^6$)	0	-218	-166	-229	-373	-342
Construction Cost ($*10^6$)	0	3973	3071	4197	6738	6166
EQ						
Mitigation (Acres)	0	1755	1345	1240	0	2972
Secondary Devel (Potential Acres)	0	1000	935	216	-334328	346000
Potential (managed ac $*10^3$)	0	132	66	175	808	42
RED						
Economic Development ($*10^6$)	0	3803	2935	4011	3220	5892
Construction ($*10^6$)	0	18790	13974	19098	15330	22081
OSE (-5 to +5)						
Public Health and Safety	0	2.00	1.23	2.54	2.62	2.46
Transportation	0	2.00	0.62	2.54	-1.69	3.08

Table 3. Collaborative Team members at workshop and at large.	
Representatives at Workshop:	Organization:
Jennifer Frazier	American Land Conservancy
Dave Ellis (Annada, MO) Dick Steinbach(Quincy, IL)	USFWS
Don Duyvejonck	USFWS-Rock Island Field Office
Mike Klingner David McMurray	Upper Mississippi, Illinois, and Missouri Rivers Association (UMIMRA)
Charlie DuCharme	Missouri DNR
Mark Beorkrem	Nicollet Island Coalition
Randy Scrivner	MO State Emergency Management Agency
Gary Clark	IL DNR Office of Water Resources
Holly Stoerker	Upper MS River Basin Association
Deanne Strauser	American Heritage Rivers
Bob Goodwin	US DOT MARAD
Note: participants combined in a single cell were paired together and produced a single weighting.	
Other members since 2002:	Organization:
Jon Kauffeld	USFWS, Region 3, Ft. Snelling, MN
Tim Yager	USFWS, Region 3, Ft. Snelling, MN
Bill Franz	USEPA, Region 5, Chicago, IL
Larry Shepard	USEPA, Region 7, Kansas City, MO
John Lucyshyn	USACE, HQ
Terry Smith	USACE, MVD
Arlen Juhl	Illinois DNR
Bill Cappuccio	Iowa DNR
Gretchen Benjamin	Wisconsin DNR
Kim Robinson	UMIMRA
Michael Reuter	The Nature Conservancy

Table 4. Corps Team members participating at the workshop.

Name	Organization
Rich Astrack	St. Louis District
Dan Hayes	Rock Island District
Jeff DeZeller	St. Paul District
Roger Perk	Rock Island District
Kevin Landwehr	Rock Island District
Dennis Stephens	St. Louis District
David Leake	St. Louis District
Dan Fetes	Rock Island District
Terry Smith	MVD

Table 5. Weights assigned to each account and metric by the Collaboration Team and the resultant cumulative weights used in multi-attribute utility analysis.

Account	Weight Mean (S.D.)	Metric	Weight Mean (S.D.)	Cumulative Weight
National Economic Development (NED)	0.207 (0.262)	NED: Benefit-to-cost ratio	0.480 (0.195)	0.099
		NED: Annual net benefits	0.270 (0.237)	0.056
		NED: Construction cost	0.250 (0.170)	0.052
Environmental Quality (EQ)	0.314 (0.324)	EQ: Managed acres	0.450 (0.247)	0.141
		EQ: Mitigation acres	0.160 (0.110)	0.050
		EQ: Secondary development	0.390 (0.292)	0.122
Regional Economic Development (RED)	0.279 (0.212)	RED: Economic development	0.640 (0.143)	0.179
		RED: Construction cost	0.360 (0.143)	0.100
Other Social Effects (OSE)	0.200 (0.240)	OSE: Public health & safety	0.455 (0.195)	0.091
		OSE: Transportation	0.237 (0.163)	0.047
		OSE: Community cohesion	0.114 (0.145)	0.023
		OSE: Controversy	0.194 (0.131)	0.039

Table 6. Summary of computation of decision scores per plan based on Collaboration Team's metric weights (*W*). *S* is the score for a particular metric (*i*), normalized across plans.

Metric (*i*)	Weight	PLAN D		PLAN E		PLAN H		PLAN J		PLAN M	
	W_i	S_i	W_iS_i	S_i	W_iS_i	S_i	W_iS_i	S_i	W_iS_i	S_i	W_iS_i
NED: Cost	0.052	0.754	0.039	1.000	0.052	0.693	0.036	0.000	0.000	0.156	0.008
NED: BCR	0.099	0.836	0.083	1.000	0.099	0.865	0.086	0.000	0.000	0.671	0.066
NED: Benefit	0.056	0.749	0.042	1.000	0.056	0.696	0.039	0.000	0.000	0.150	0.008
EQ: Managed acres	0.141	0.117	0.016	0.031	0.004	0.174	0.025	1.000	0.141	0.000	0.000
EQ: Mitigation acres	0.050	0.409	0.020	0.547	0.027	0.583	0.029	1.000	0.050	0.000	0.000
EQ: 2nd Development	0.122	0.507	0.062	0.507	0.062	0.191	0.023	1.000	0.122	0.000	0.000
RED: Cost	0.100	0.594	0.059	0.000	0.000	0.632	0.063	0.168	0.017	1.000	0.100
RED: Econ Develop	0.179	0.294	0.053	0.000	0.000	0.364	0.065	0.096	0.017	1.000	0.179
OSE: Controversy	0.039	0.999	0.039	0.938	0.037	0.755	0.029	0.001	0.000	0.714	0.028
OSE: Cohesion	0.023	0.811	0.019	0.767	0.018	0.681	0.016	0.000	0.000	0.999	0.023
OSE: Transportation	0.047	0.774	0.036	0.483	0.023	0.886	0.042	0.000	0.000	0.999	0.047
OSE: Public H&S	0.091	0.554	0.050	0.001	0.000	0.941	0.086	0.996	0.091	0.886	0.081
Standard deviation		0.253		0.424		0.255		0.478		0.446	
Mean		0.617		0.523		0.622		0.355		0.548	
SD/Mean		0.411		0.811		0.411		1.347		0.813	
Sum			0.519		0.378		0.538		0.438		0.540

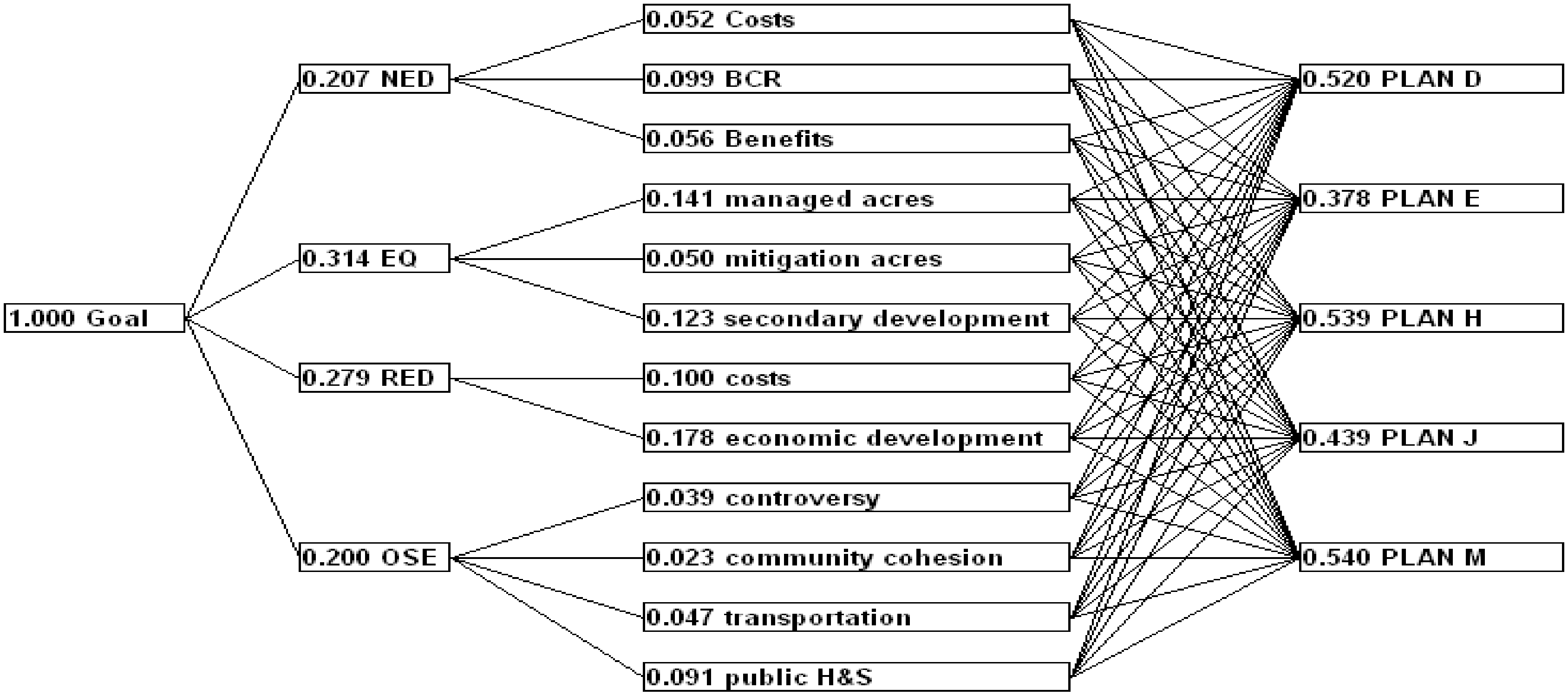


Figure 3. Hierarchy showing cumulative metric weights and decision scores for each alternative, Collaboration Team .

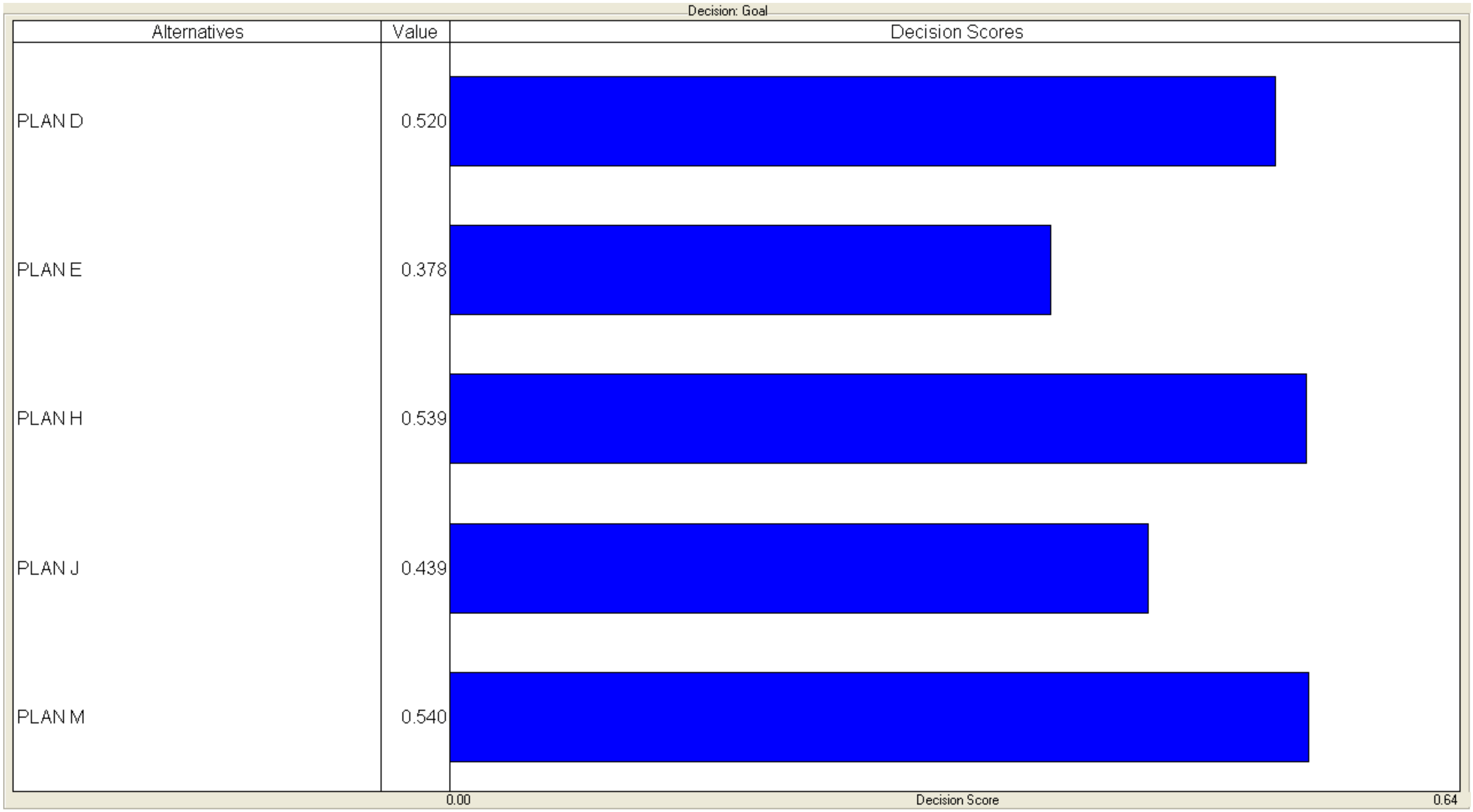


Figure 4. Decision scores for each alternative based on metric weights of the Collaboration Team.

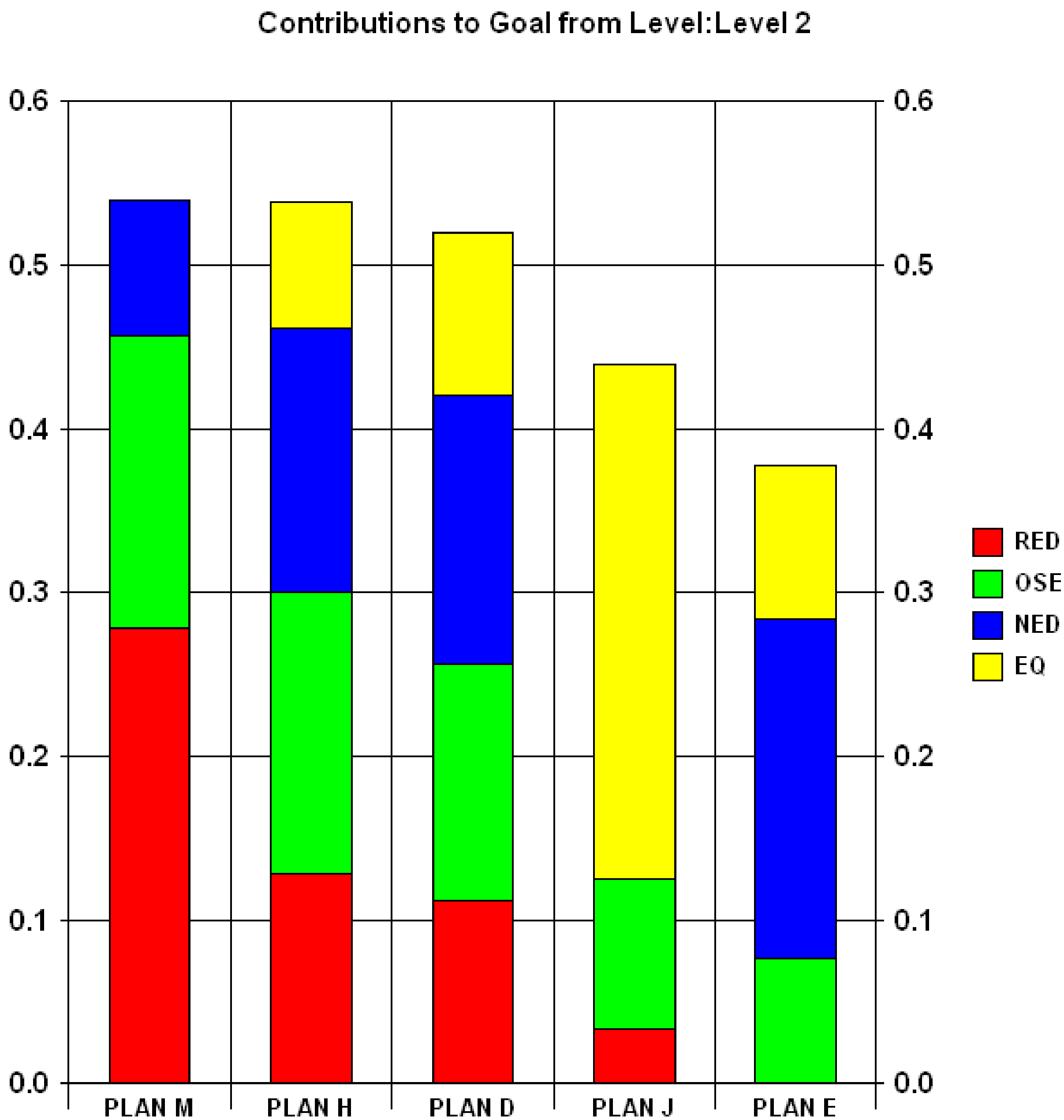


Figure 5. Contributions of NED, OSE, EQ, and RED to each alternative using Collaboration Team's weights.

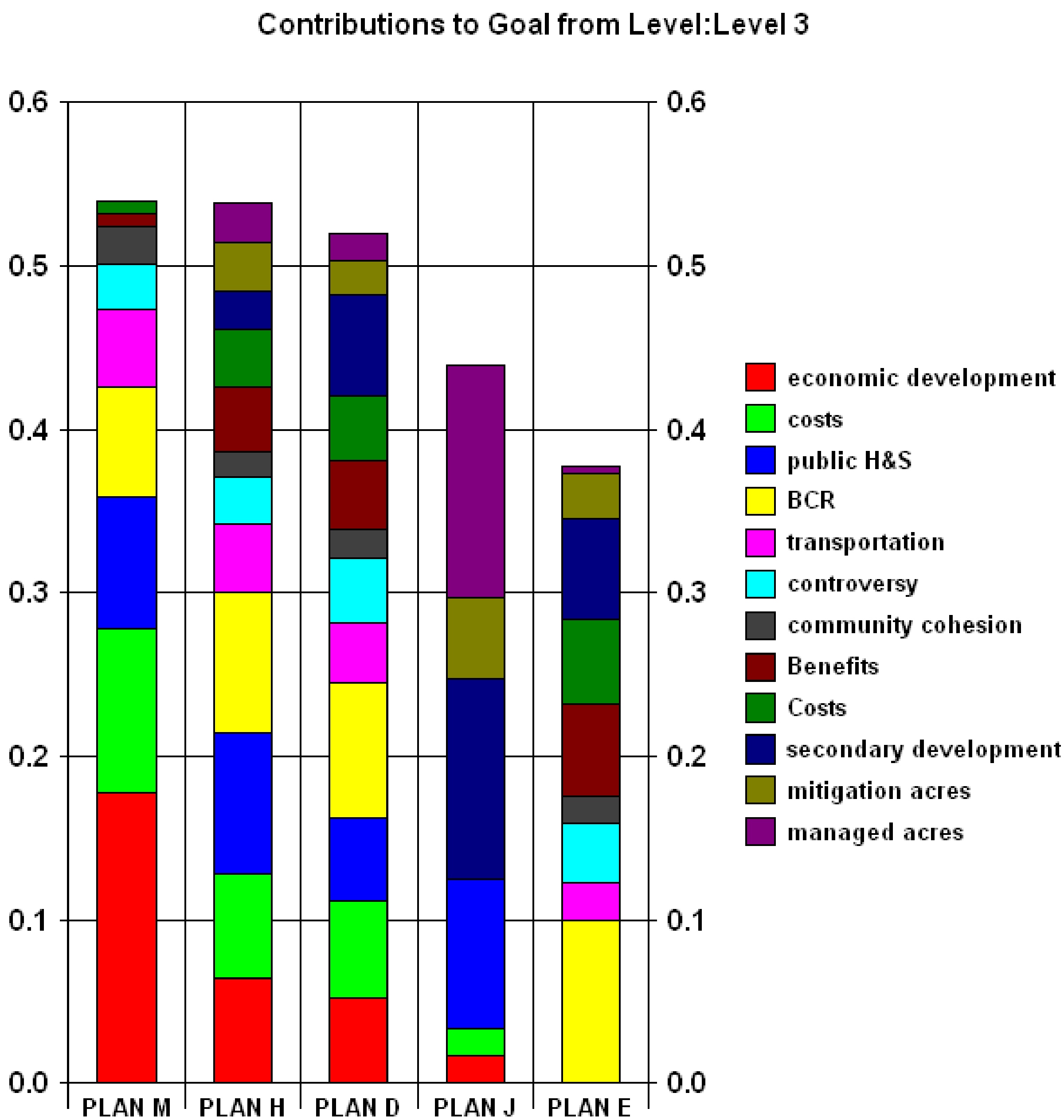


Figure 6. Contributions of each metric to decision scores of alternatives using Collaboration Team's weights.

Collaboration Team: Sensitivity to Uncertainty of Metric Weights. Results summarized thus far reflect an average stakeholder view. It is difficult to parse the views of a group into individuals, for a variety of reasons. A relevant tool that multi-criteria decision analysis provides to evaluate different views of metric weights is *sensitivity analysis*. Sensitivity analysis shows how decision scores for all plans change with changing weight of a particular metric. This can be done for each individual metric. Sensitivity plots are provided for the 12 metrics in Appendix A.

Herein are presented just the sensitivity plots for the Collaboration Team model results with respect to the four system of accounts (Figures 7-10). Figures 7 and 8 indicate how modest shifts in the weight of the NED or EQ would alter the order of plan rankings in the decision model. In contrast, Figure 10 for OSE is an example of a situation in which a much more substantial weight change is needed to much affect the decision outcomes. Steeply sloping lines, a blend of positive and negative linear relationships, and a mean that happens to occur near a pivot point all combine to make decision outcomes more sensitive to a particular metric's weight change. In this fashion, sensitivity analysis allows individuals that might disagree with the mean weight assigned to a particular metric to readily see if and how decision scores would have been affected by different metric weights.

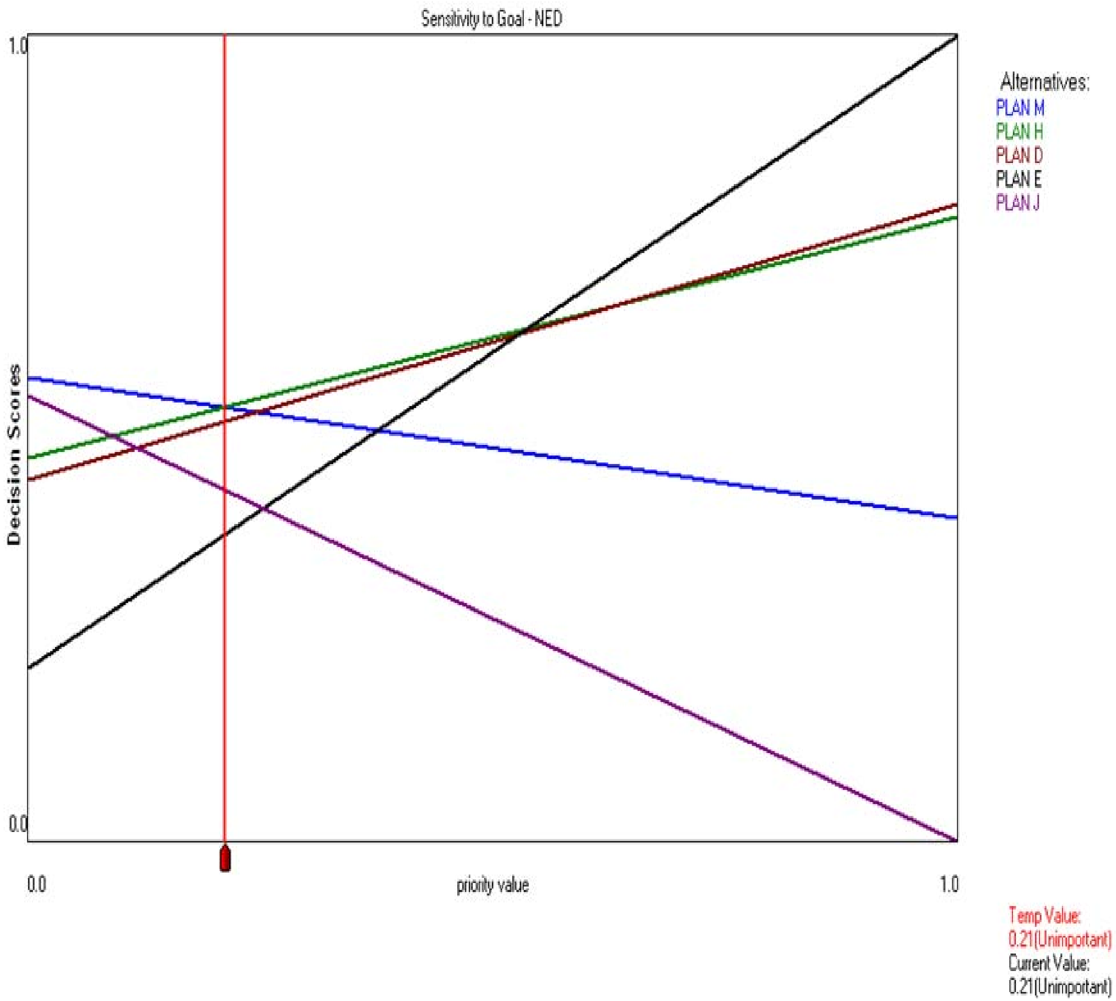


Figure 7. Sensitivity of decision scores to NED based on Collaboration Team's weights. The red vertical line shows the mean weight; a slight increase would shift the order of plans H and M.

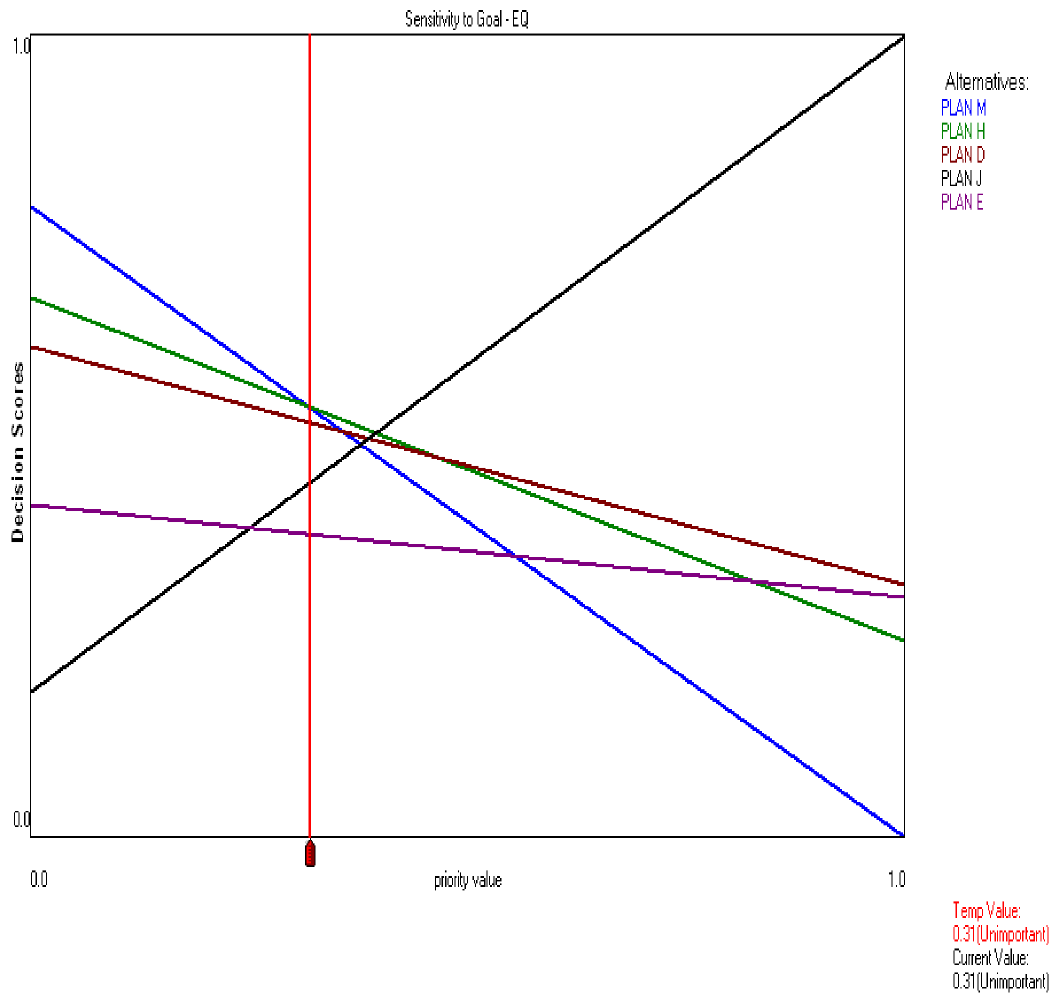


Figure 8. Sensitivity of decision scores to weight of EQ based on the Collaboration Team's weights. The red vertical line indicates the mean weight; a moderate decrease benefits Plan M relative to Plan H.

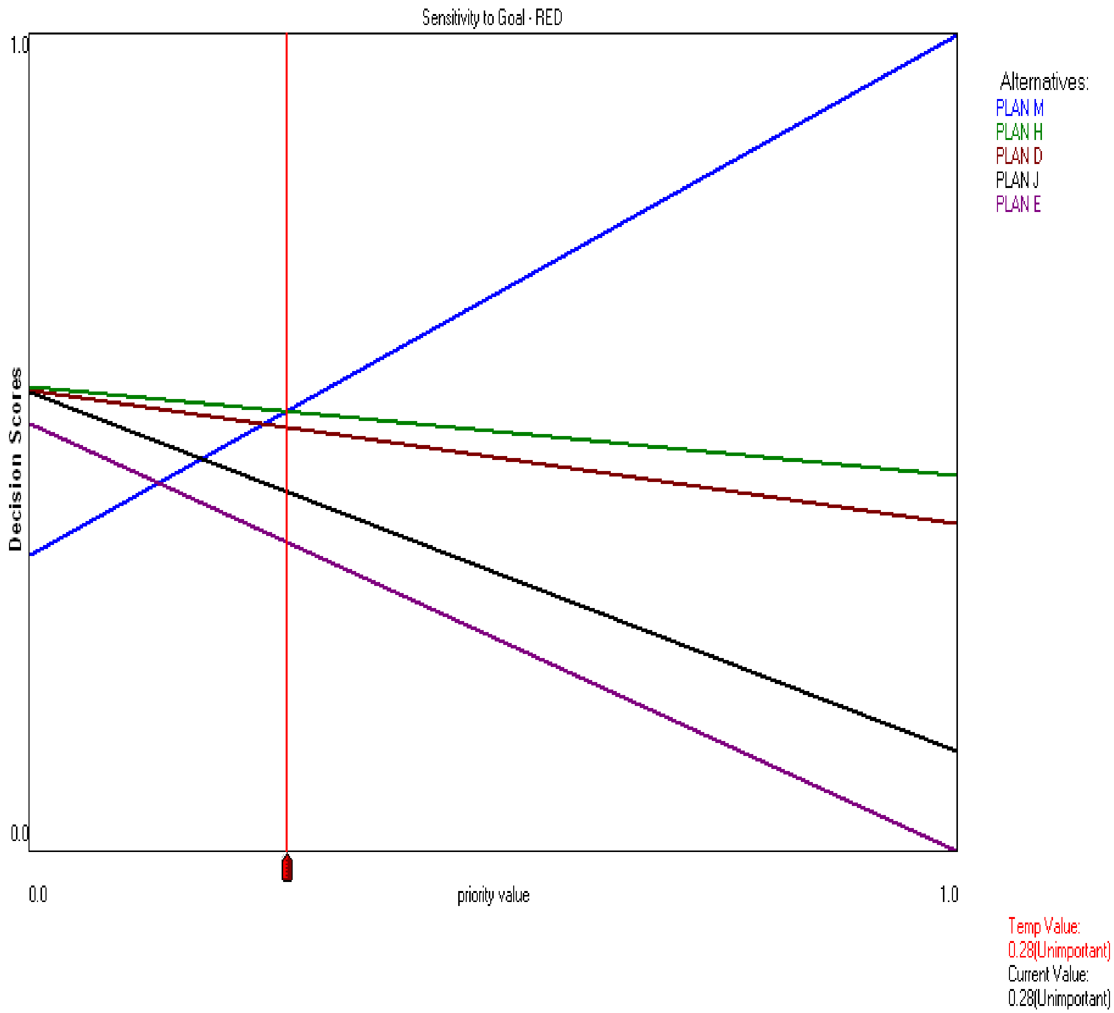


Figure 9. Sensitivity of decision scores to weight of RED based on the Collaboration Team's weight. The red vertical line indicates the mean weight; higher weighting greatly increased the decision score of Plan M.

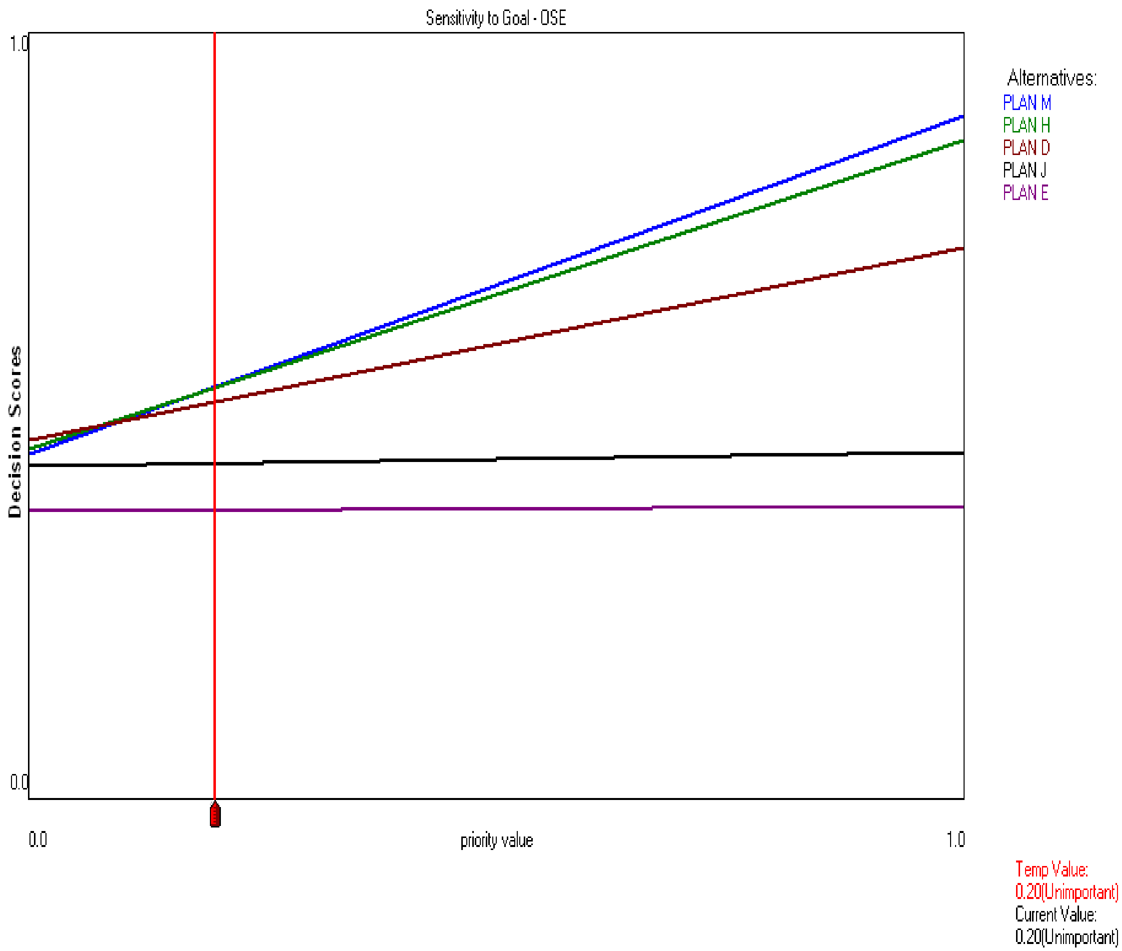


Figure 10. Sensitivity of decision scores to weight of OSE based on the Collaboration Team's weights. The red vertical line indicates the mean weight; a substantial change is required to substantially affect plans' relative scores.

Corps Team: Metric Weights and Decision Scores. Table 7 summarizes the weights elicited from the Corps Team for system accounts (NED, EQ, RED, and OSE), the metrics within each account, and the cumulative weight of each metric. The diversity of stakeholder opinions represented on the Collaboration Team was not reflected by these results for the Corps Team. In general, the ratio of the standard deviation-to-mean was less than 0.5 and often considerable less. Thus, as might be anticipated, the Corps Team was relatively uniform in their view of how accounts and metrics within each account should be weighted. Thus, there was greater consistency of opinion concerning the cumulative weights to be used as inputs in the decision model.

Figure 11 graphical display the hierarchy of account level and cumulative metric weights along with the resultant decision scores for each plan. For the Corps Team's weightings, these decision scores were 0.63, 0.59, 0.57, 0.46, and 0.37 for plans H, D, E, M, and J, respectively. The relative decision scores of the five alternative plans are graphically portrayed in Figure 12, showing the relatively tight clustering of plans H, D, and E relative to M and J.

As earlier discussed, Table 8 summarizes the computation of the decision scores and provides information on performance with respect to each metric. As for the Collaboration Team results, two of the relatively high scoring plans, H and D, were ones that showed relatively high balance in their performance against the entire metric lists. The other high scoring alternative, Plan E, depended more on NED metrics and not all on RED metrics.

Figures 13 and 14 graphically demonstrate a moderately high contribution of NED and its component metrics to the high decision scores of plans H, D, and E. Nonetheless, among these three plans, both H and D showed greater balance among metric contributions than did Plan E. Overall, there was less balance among metrics for the Corps than the Collaboration team's results. This is not surprising given the wide diversity of stakeholder views that collectively resulted in the Collaboration Team's metric weightings.

Table 7. Weights assigned to each account and metric by the Corps Team and the resultant cumulative weights used in multi-attribute utility analysis.

Account	Weight Mean (S.D.)	Metric	Weight Mean (S.D.)	Cumulative Weight
National Economic Development (NED)	0.423 (0.144)	NED: Benefit-to-cost ratio	0.490 (0.143)	0.207
		NED: Annual net benefits	0.339 (0.160)	0.143
		NED: Construction cost	0.172 (0.080)	0.073
Environmental Quality (EQ)	0.267 (0.123)	EQ: Managed acres	0.517 (0.171)	0.138
		EQ: Mitigation acres	0.267 (0.150)	0.071
		EQ: Secondary development	0.217 (0.135)	0.058
Regional Economic Development (RED)	0.117 (0.056)	RED: Economic development	0.644 (0.161)	0.075
		RED: Construction cost	0.356 (0.161)	0.042
Other Social Effects (OSE)	0.189 (0.065)	OSE: Public health & safety	0.472 (0.156)	0.089
		OSE: Transportation	0.228 (0.091)	0.043
		OSE: Community cohesion	0.156 (0.077)	0.029
		OSE: Controversy	0.144 (0.092)	0.027

Table 8. Summary of computation of decision scores per plan based on Corps Team's metric weights (*W*). *S* is the score for a particular metric (*i*), normalized across plans.

Metric (*i*)	Weight	PLAN D		PLAN E		PLAN H		PLAN J		PLAN M	
	W_i	S_i	W_iS_i	S_i	W_iS_i	S_i	W_iS_i	S_i	W_iS_i	S_i	W_iS_i
NED: Cost	0.074	0.754	0.056	1.000	0.074	0.693	0.051	0.000	0.000	0.456	0.012
NED: BCR	0.209	0.836	0.175	1.000	0.209	0.865	0.181	0.000	0.000	0.671	0.140
NED: Benefit	0.143	0.749	0.107	1.000	0.143	0.696	0.100	0.000	0.000	0.150	0.021
EQ: Managed	0.138	0.117	0.016	0.031	0.004	0.174	0.024	1.000	0.138	0.000	0.000
EQ: Mitigation	0.071	0.409	0.029	0.547	0.039	0.583	0.042	1.000	0.071	0.000	0.000
EQ: Development	0.058	0.507	0.029	0.507	0.029	0.191	0.011	1.000	0.058	0.000	0.000
RED: Cost	0.042	0.594	0.025	0.000	0.000	0.632	0.026	0.168	0.007	1.000	0.042
RED: Development	0.075	0.294	0.022	0.000	0.000	0.364	0.027	0.096	0.007	1.000	0.075
OSE: Controversy	0.027	0.999	0.027	0.938	0.026	0.755	0.021	0.001	0.000	0.714	0.019
OSE: Cohesion	0.029	0.811	0.024	0.767	0.023	0.681	0.020	0.000	0.000	0.999	0.029
OSE: Transportation	0.043	0.774	0.033	0.483	0.021	0.886	0.038	0.000	0.000	0.999	0.043
OSE: Public H&S	0.089	0.554	0.049	0.001	0.000	0.941	0.084	0.996	0.089	0.886	0.079
Standard deviation		0.253		0.424		0.255		0.478		0.446	
Mean		0.617		0.523		0.622		0.355		0.548	
SD/Mean		0.411		0.811		0.411		1.347		0.813	
		Sum	0.595		0.568		0.625		0.370		0.461

Corps Team: Sensitivity to Uncertainty of Metric Weights. Sensitivity analyses for NED, EQ, RED, and OSE (Figures 15-18) did not suggest a slight change in the weighting of any account would have greatly altered the relative ranking of alternative plans. Although the slopes of lines in Figures 15-18 were often high, and both positive and negative relationships were apparent, the average weight assigned to the accounts by the Corps Team were not closely adjacent to pivot points on these curves. This was true despite the relatively close match of decision scores for Plans H, D, and E.

Sensitivity plots for the twelve individual metrics are provided in Appendix A.

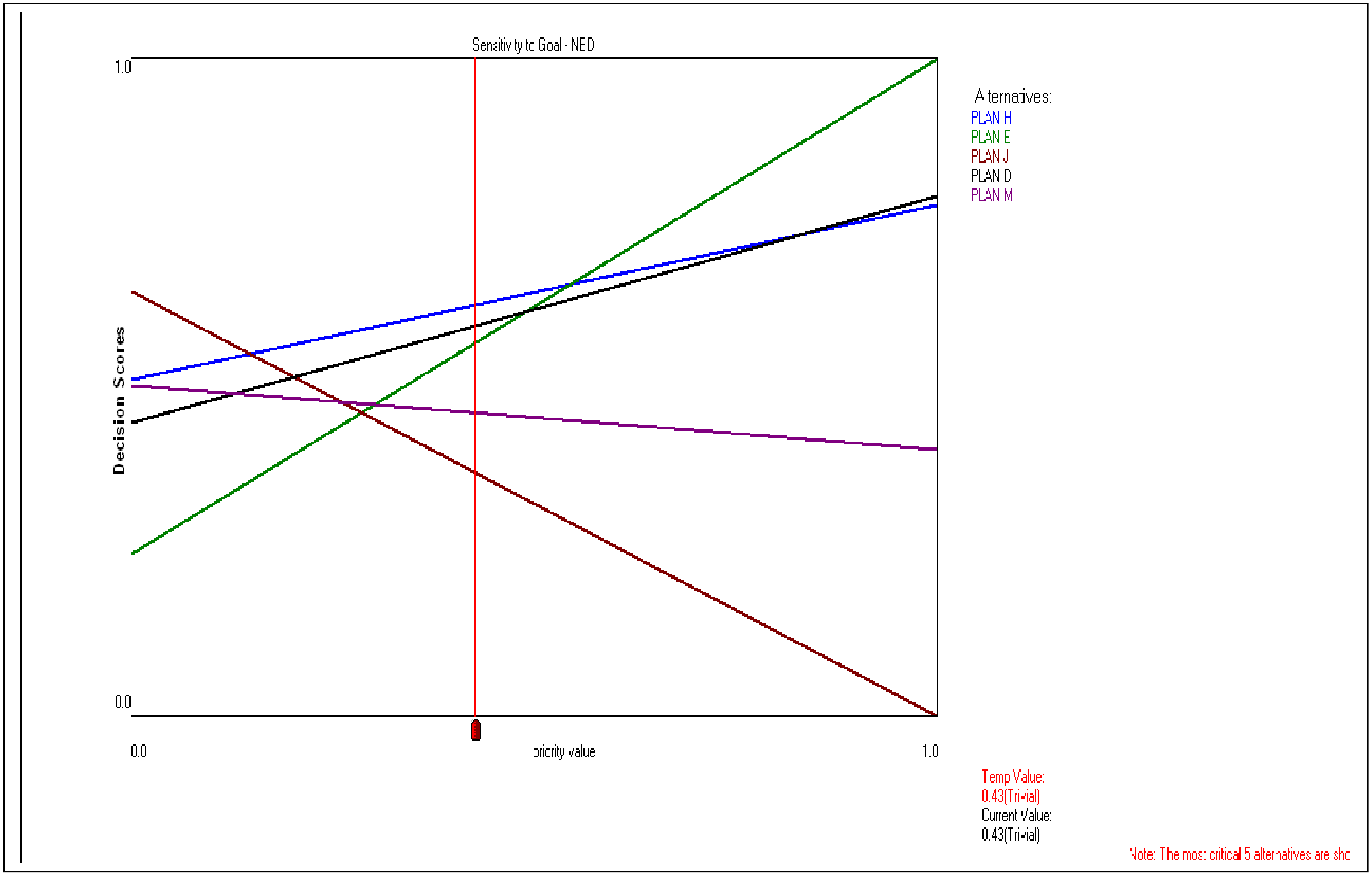


Figure 15. Sensitivity of decision scores to NED based on Corps Team's weights.

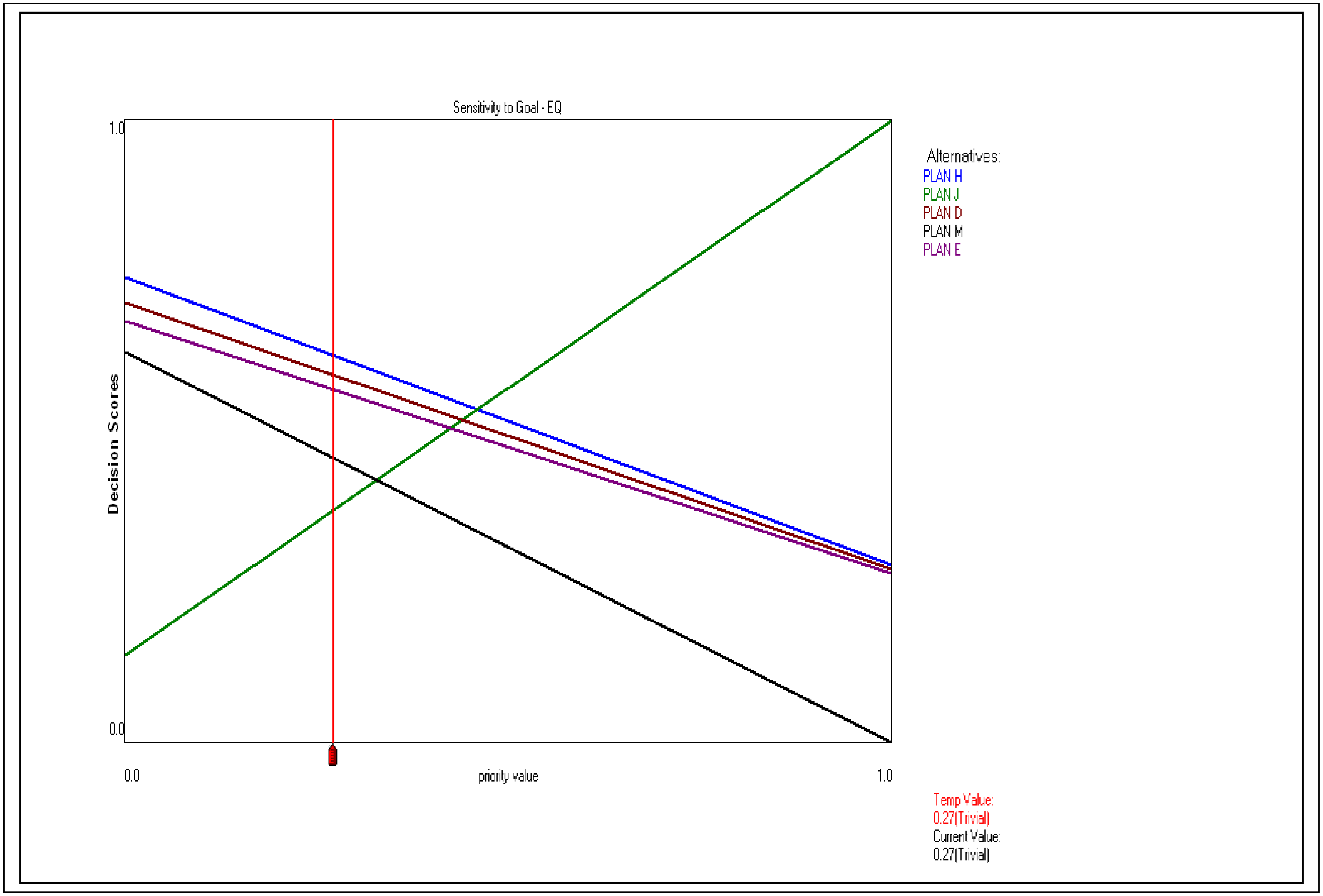


Figure 16. Sensitivity of decision scores to weight of EQ based on Corps Team's weights.

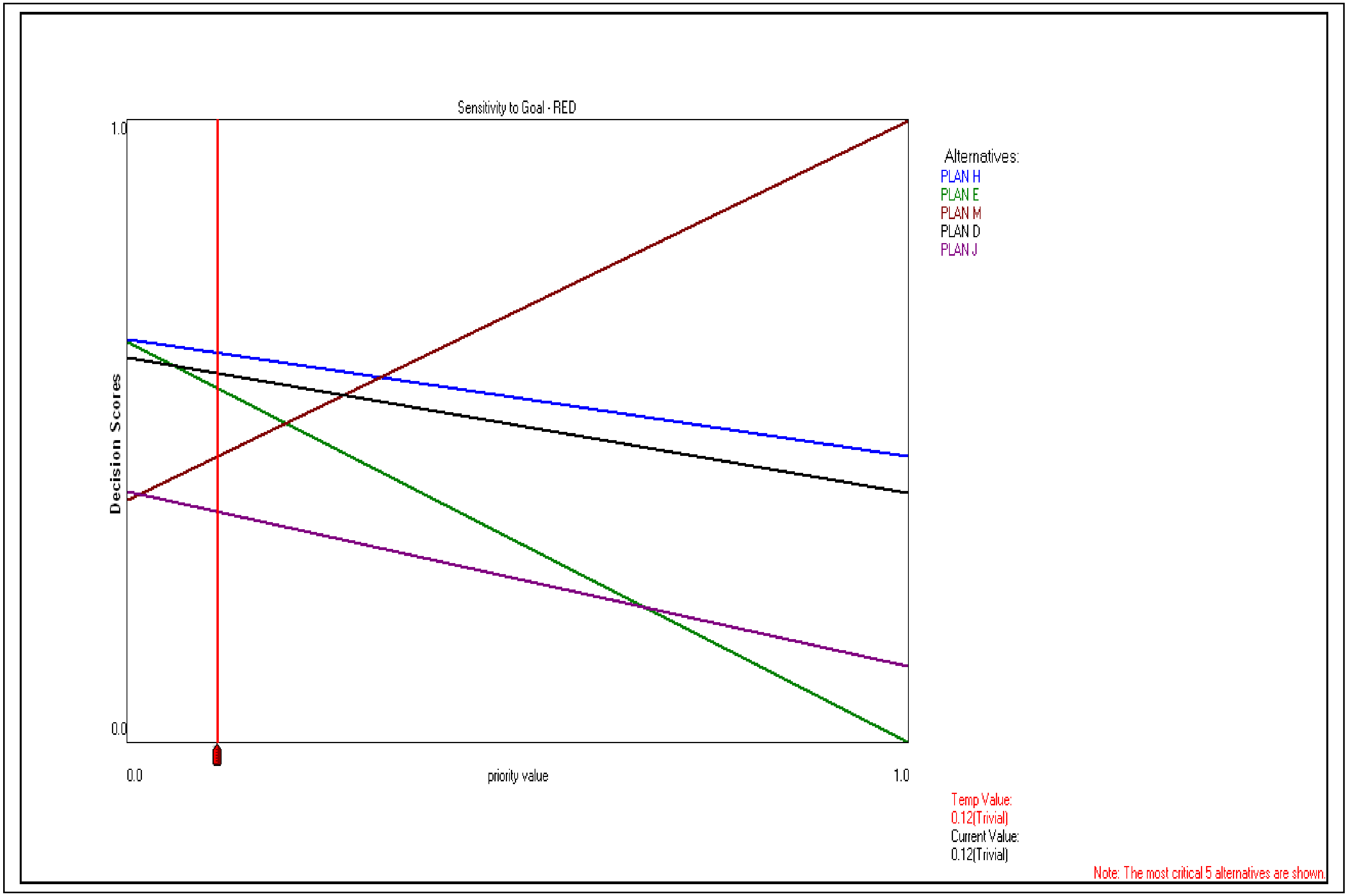


Figure 17. Sensitivity of decision scores to weight of RED based on Corps Team's weight.

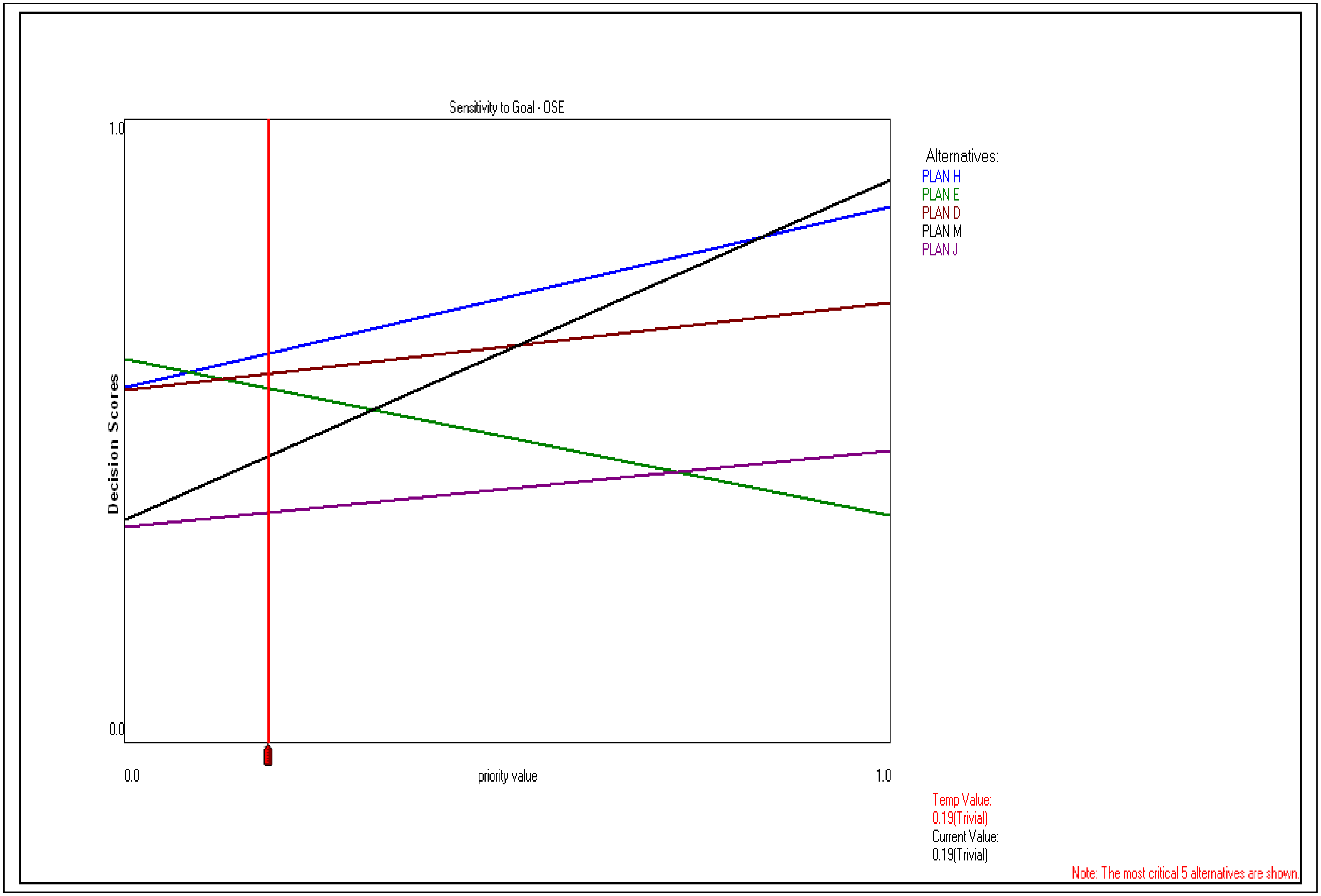


Figure 18. Sensitivity of decision scores to weight of OSE based on Corps Team's weights.

Summary Comparisons. A simple, summary comparison of the Collaboration and Corps Team models is shown below.

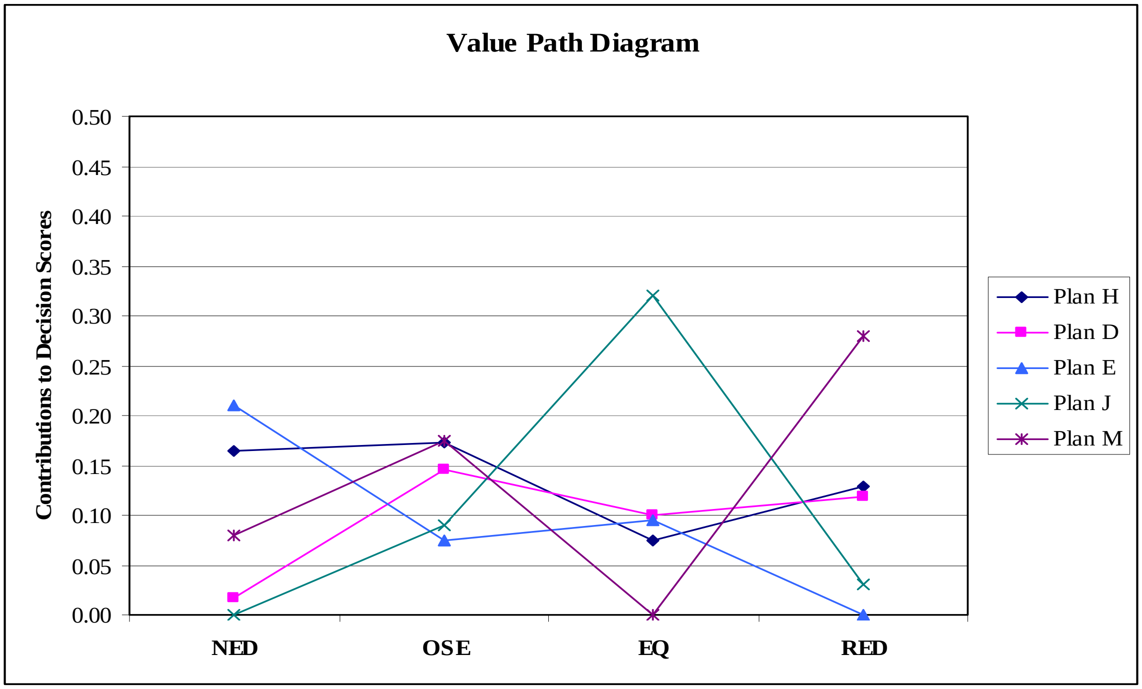
	Decision Score per Plan				
	D	E	H	J	M
Corps Team	*0.59*	0.57	*0.63*	0.37	0.46
Collaboration Team	0.52	0.38	*0.54*	0.44	*0.54*

The two top-scoring plans under each set of metric weights have their decision scores highlighted. Plan H was a high-scoring alternative for both groups. Plan M faired well under the mean weights applied by the Collaboration Team but much less well under the weights used by the Corps Team. Plan D scored well, but not quite as high, in both teams' models.

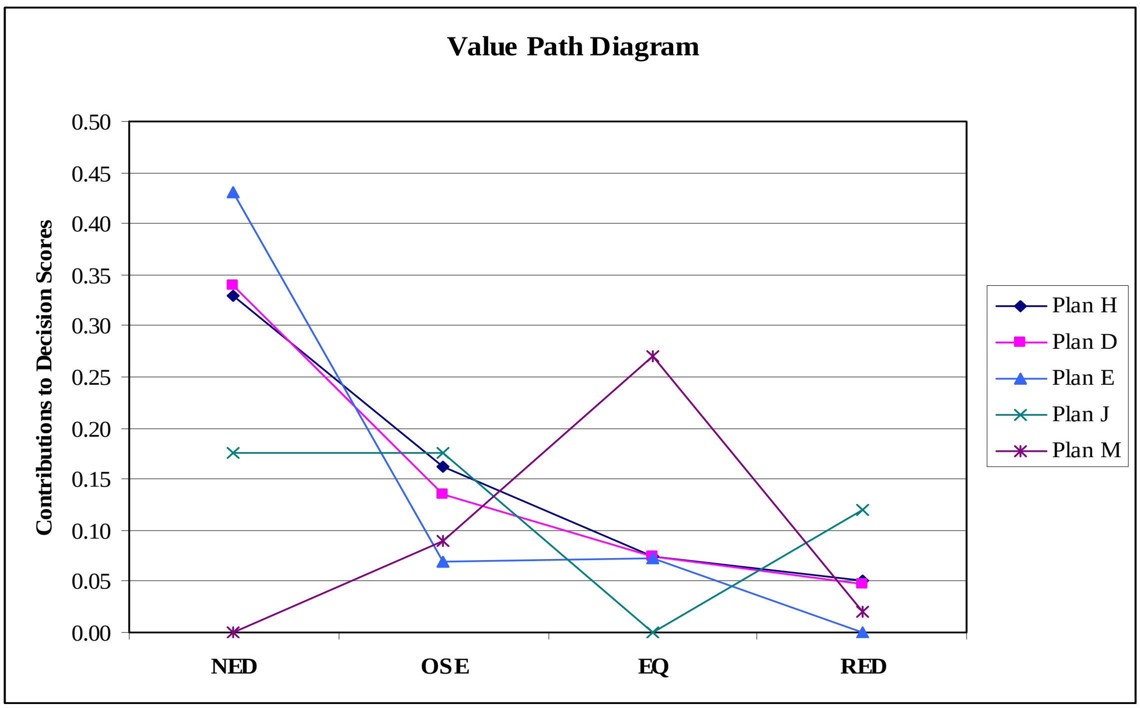
Furthermore, Plan H showed relatively balanced performance against the full list of metrics or accounts. An important outcome of a multi-criteria decision analysis is not just the decision score, but more detailed consideration of the relative contributions of performance metrics to the decision score.

Figure 19 summarizes the results of trade-off analyses of the five plans for both teams. Trade-off analysis shows how plans perform in relation to potentially conflicting objectives and their associated metrics. The tradeoff method used in Figure 19 is the "value path" approach (Bishop, 1974). The horizontal axis represents different metrics (for clarity of communication, the System of Accounts level is used) and the vertical axis represents the contribution of each plan relative to each metrics.

This portrayal directly reveals if one or more alternative plans are clearly dominated by another plan with respect to every objective. Any such dominated plan simply could be dropped from further consideration. However, this was not the case among the UMRCP plans. Rather, Figure 19 once again shows the relative balance among accounts of metrics for the five plans. Plans H, D, and, to a lesser extent E, show greater balance among multiple objectives than do Plans M and J. Plans H, D, and, especially E, score high with respect to NED, with progressively lower contributions of OSE, EQ, and RED, respectively. Plan J depends highly on EQ, which makes no contribution for Plan M. These general patterns of results are evident in both the Collaboration and Corps teams' decision models.



Collaboration Team



Corps Team

Figure 19. Trade-offs among plans in contributions of NED, OSE, EQ, and RED to decision scores. The Collaboration and Corps team results are shown in the top and bottom figures, respectively.

Conclusions

As demonstrated by our results, plan selection is a group decision process from which no a single "best" solution will necessarily emerge. Still, multiple criteria and perspectives are dealt with in a transparent fashion. Plan H, and to a lesser extent Plan D, emerged as a high-scoring alternative regardless of whether weights for performance metrics were assigned by the diverse Collaboration Team or less diverse Corps Team.
Both plans showed substantially balanced performance against multiple metrics.

Thus, the multi-criterion decision analyses presented herein identified not only the relatively high-scoring alternatives, but also the abilities of these alternatives to meet multiple objectives. Because individuals think about the various metrics in slightly different ways and the hold a diversity of views about the relative importance of particular objectives, such balance is probably important. Ideally, these results should be shared with members of both teams now that their views have been captured and used to fully compare alternatives. Revisiting the issue with these results in hand would allow individuals to check their thinking and correct any misconceptions, if necessary. Like plan formulation, plan evaluation and the attendant decision process should be iterative.

The final step in the planning process is to select a recommended plan for more detailed consideration and implementation. The results summarized herein are best viewed as **informing** decision-makers. The differences between plans H and D are not great. Yet both are distinct from plans M and J in that H and D do a better job of balancing multiple objectives.

It is important that these results were developed in a transparent way and integrated the inputs of diverse stakeholder interests. Care was taken not to let factors germane to the decision remain outside the formal scoring and ranking process. In other words, the decision model implemented herein included all of the principal concerns, objectives, and factors that were relevant to this decision process. Furthermore, the tools used in stakeholder weight elicitation and plan evaluation promoted clearer visualization and communication of the potential sociological, economic and ecological outcomes of different alternative plans. Great care was taken to ensure that the process was comprehensive in approach and sensitive to the interests and values of the many parties affected by decision surrounding system-wide flood protection of the Upper Mississippi River system.

Key strengths of risk-informed decisions involving multiple criteria and stakeholders are the explicit incorporation of the values of decision-makers and stakeholders through the definition and relative weighting of metrics, an ability to address uncertainty in scoring and ranking of measures, and the overall transparency decision process. The process reported herein supported the following critical aspects of the decision-making process (Hobbs and Meier, 2000) by:

- *Systematically structured the decision process:* MCDA helps decision makers think systematically about the problem by providing a logical framework for defining plans, and comparing performance based on pre-established metrics;
- *Displayed tradeoffs among metrics* so that managers and stakeholders can understand the relative advantages and disadvantages of plans;
- *Helped decision makers and stakeholders reflect upon, articulate, and apply explicit value judgments concerning conflicting criteria and uses.* During the course of a decision process, people's attitudes will evolve in response to new information, interactions with others, and viewing the problem from different perspectives; MCDA offers the means to document this evolution and explain the resulting ranks.
- *Provided as basis for negotiation.* By detailing how each of the steps of the decision-making process has been conducted, decision makers can communicate and defend the basis of their decisions to stakeholders and other interested parties.

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Appendix A

This appendix consists of a series of 24 figures. The first twelve (Figures 1A-12A) present sensitivity plots showing the weight assigned to each performance metric and indicating how plans' decision scores change as each metric's weight is changed. These first twelve figures are based on weights assigned by the Collaboration Team. The next twelve figures (13A-24A) provide similar information, but are based upon the weight assignments of the Corps Team.

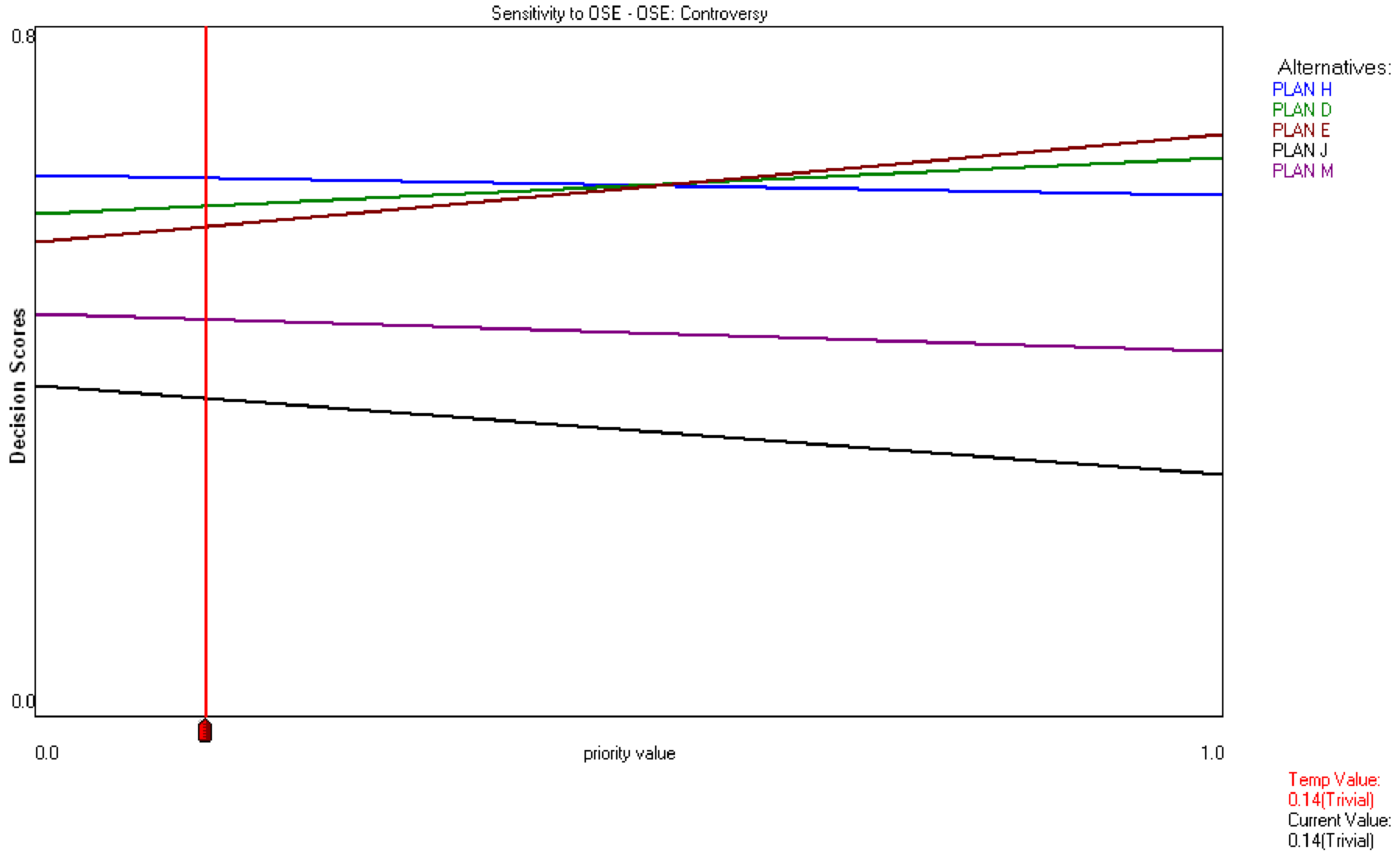

Figure 24A. Sensitivity of decision scores to OSE: Controversy based on Corps Team's weights.

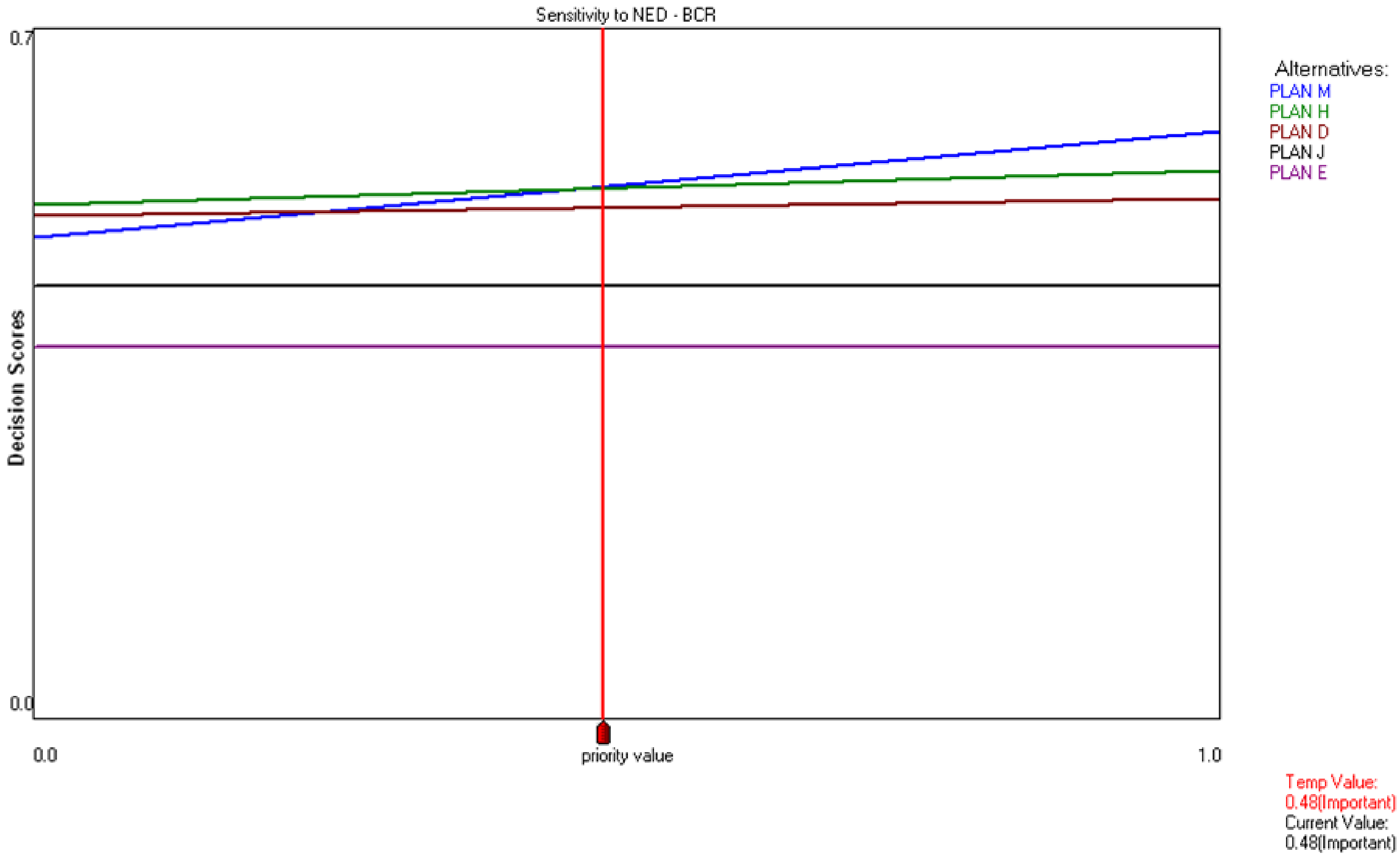

Figure 1A. Sensitivity of decision scores to NED: Benefit-to-Cost Ratio based on Collaboration Team's weights.

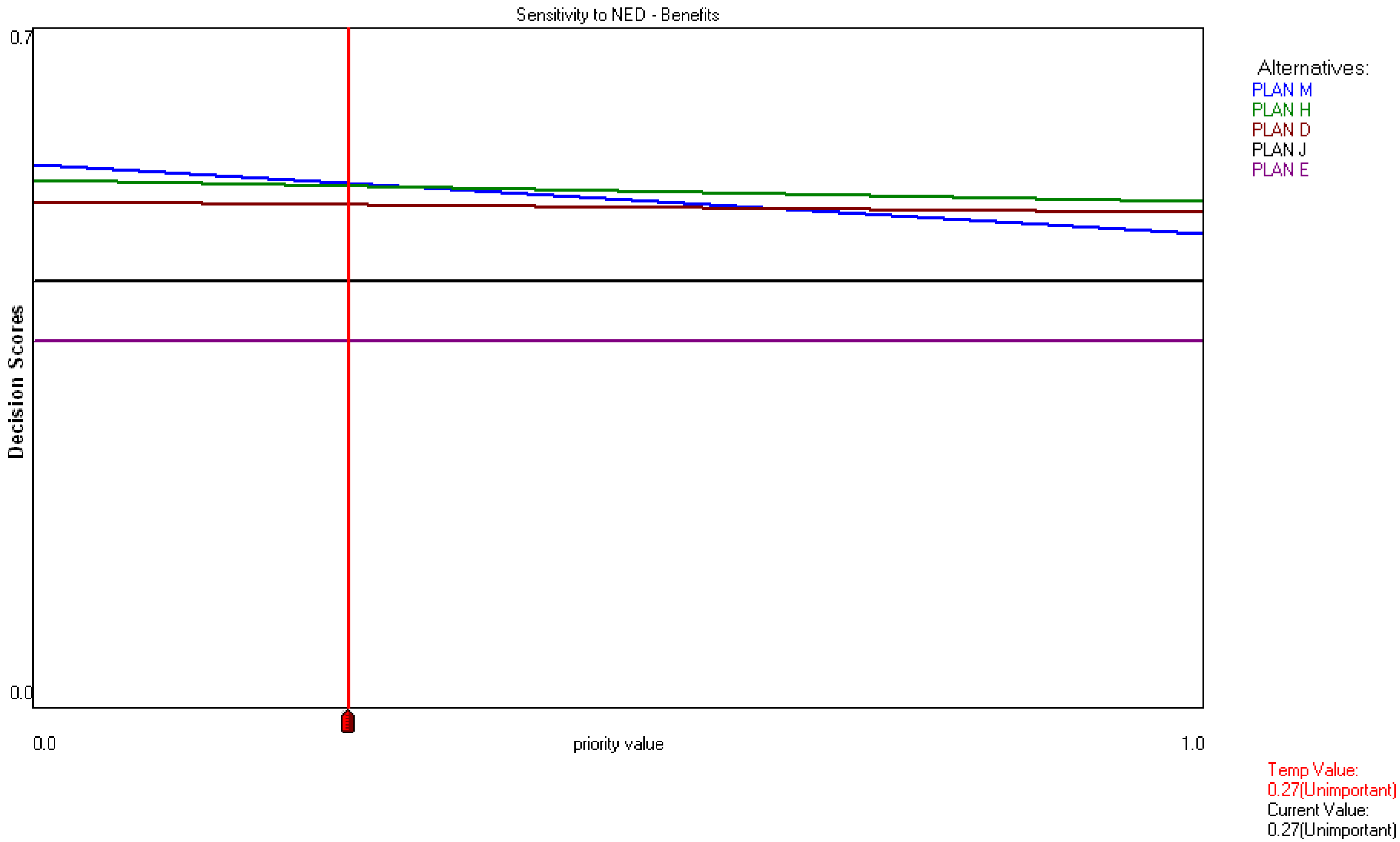

Figure 2A. Sensitivity of decision scores to NED: Annual Net Benefits based on Collaboration Team's weights.

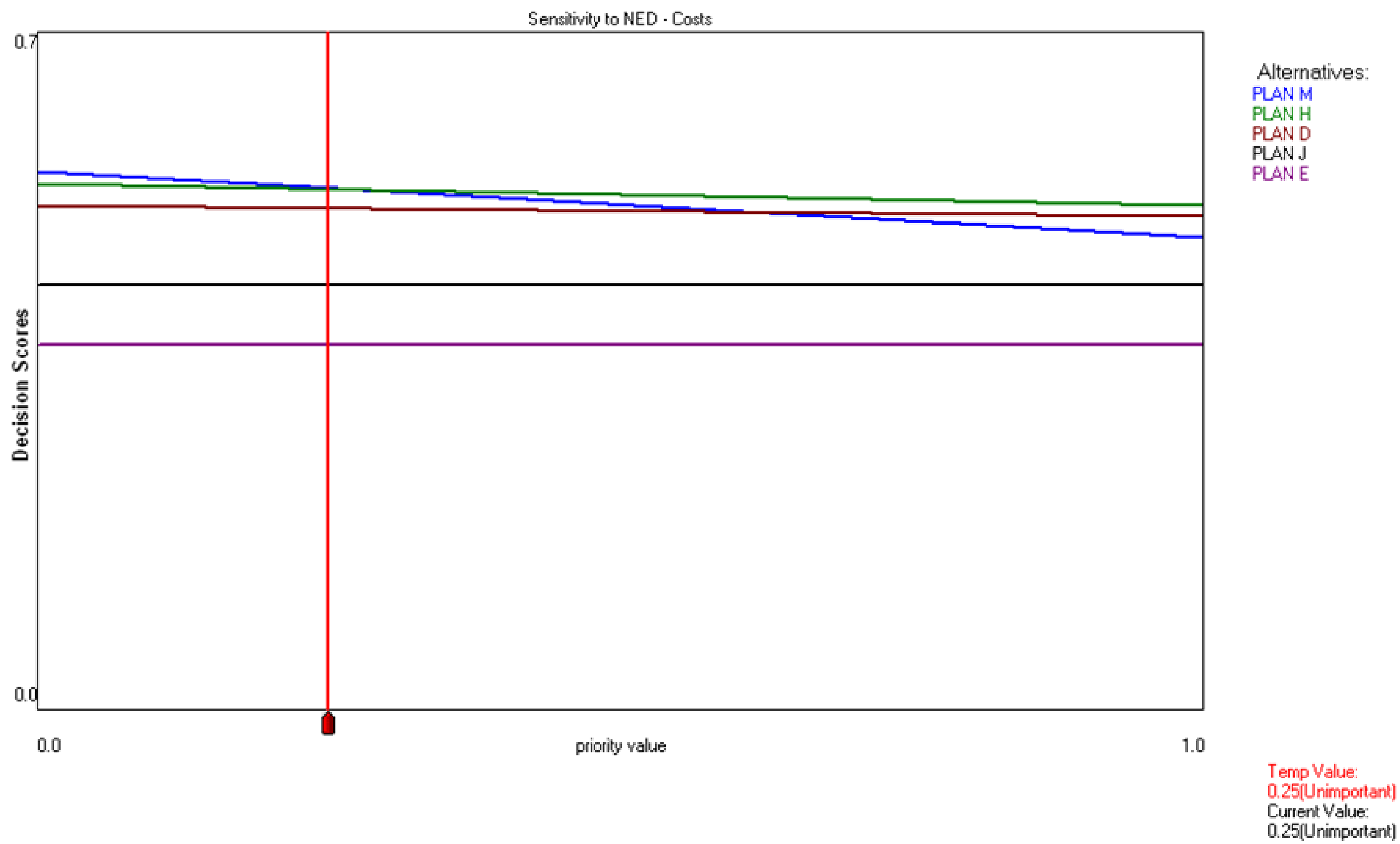

Figure 3A. Sensitivity of decision scores to NED: Construction Cost based on Collaboration Team's weights.

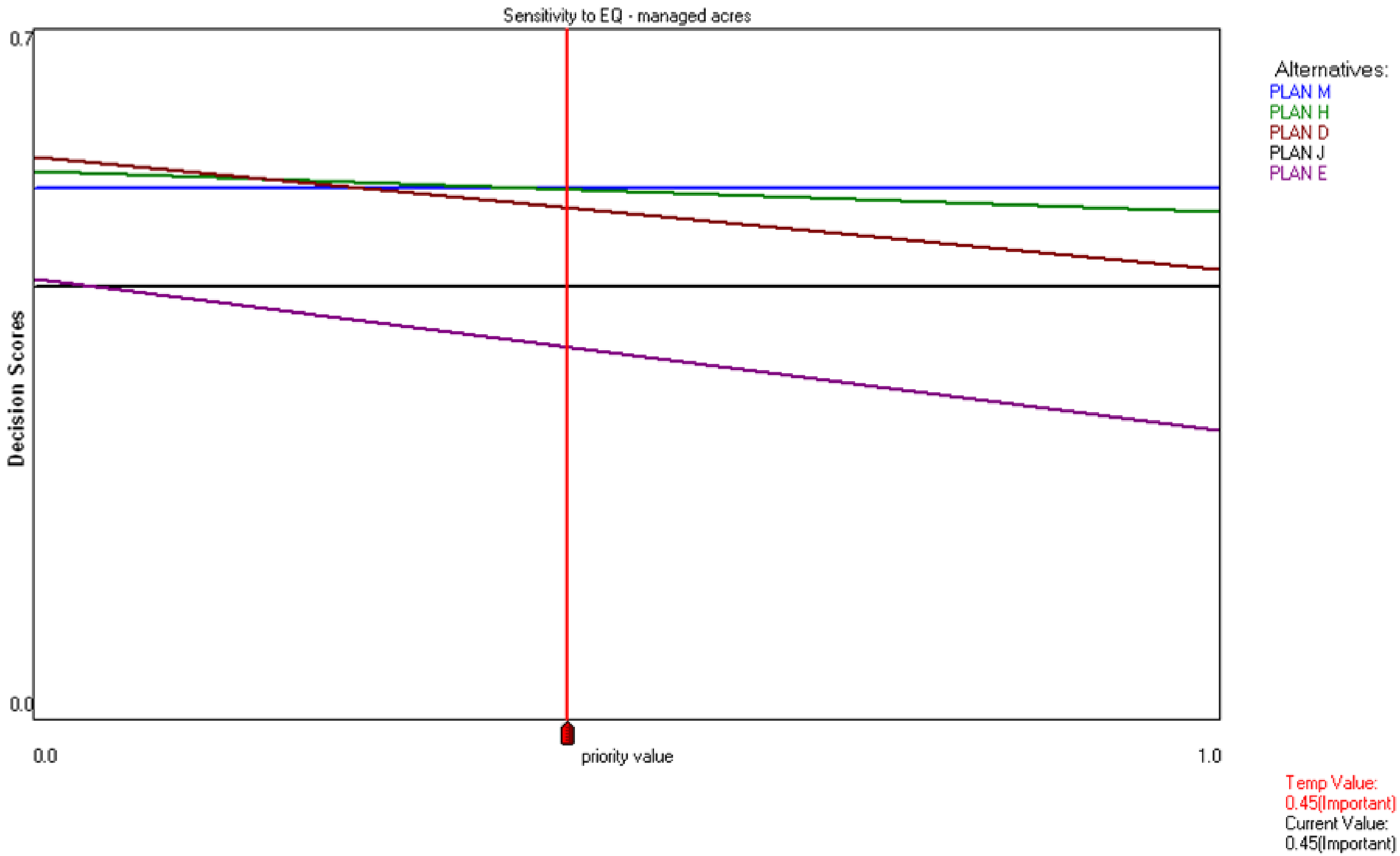

Figure 4A. Sensitivity of decision scores to EQ: Managed Acres based on Collaboration Team's weights.

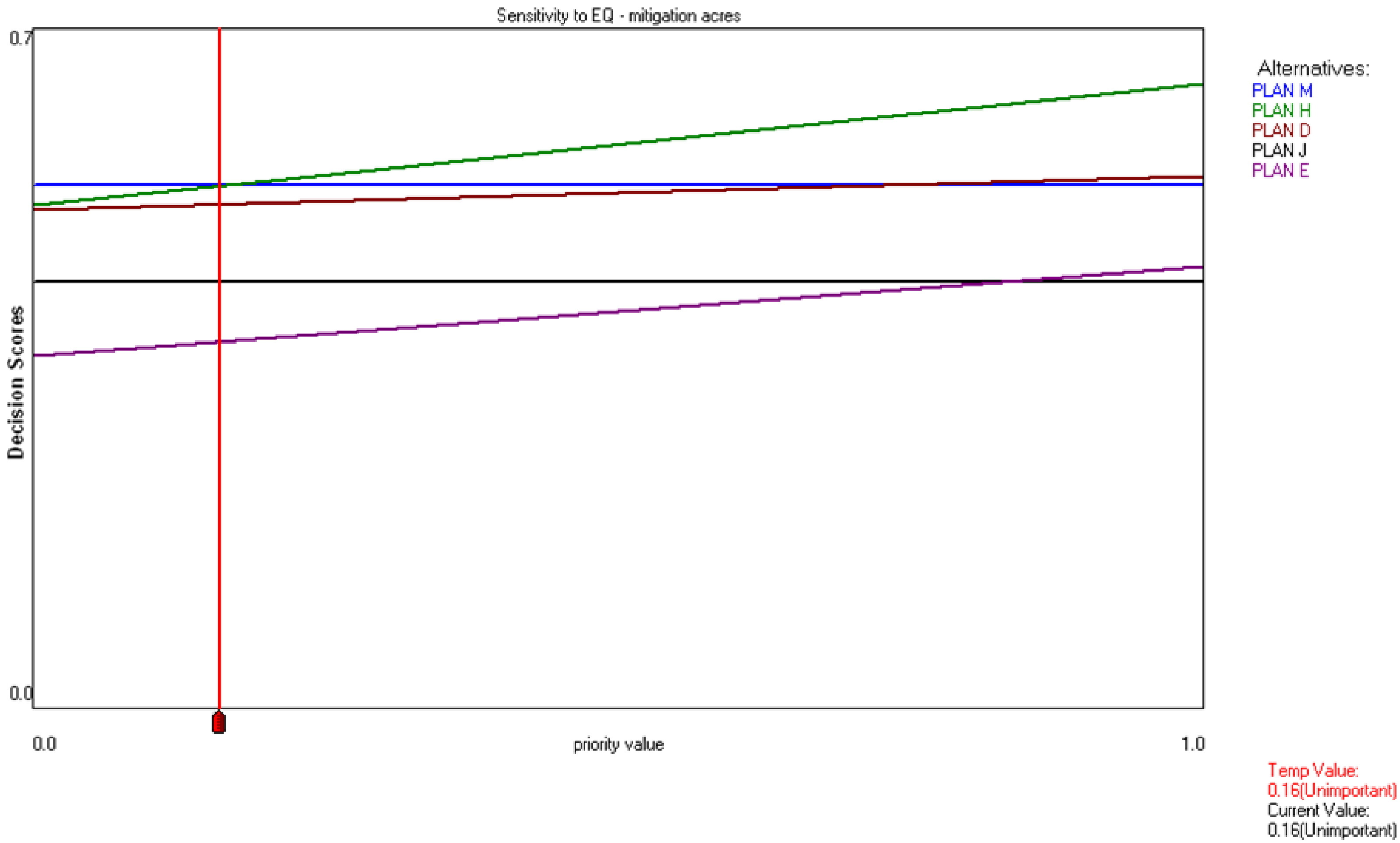

Figure 5A. Sensitivity of decision scores to EQ: Mitigation Acres based on Collaboration Team's weights.

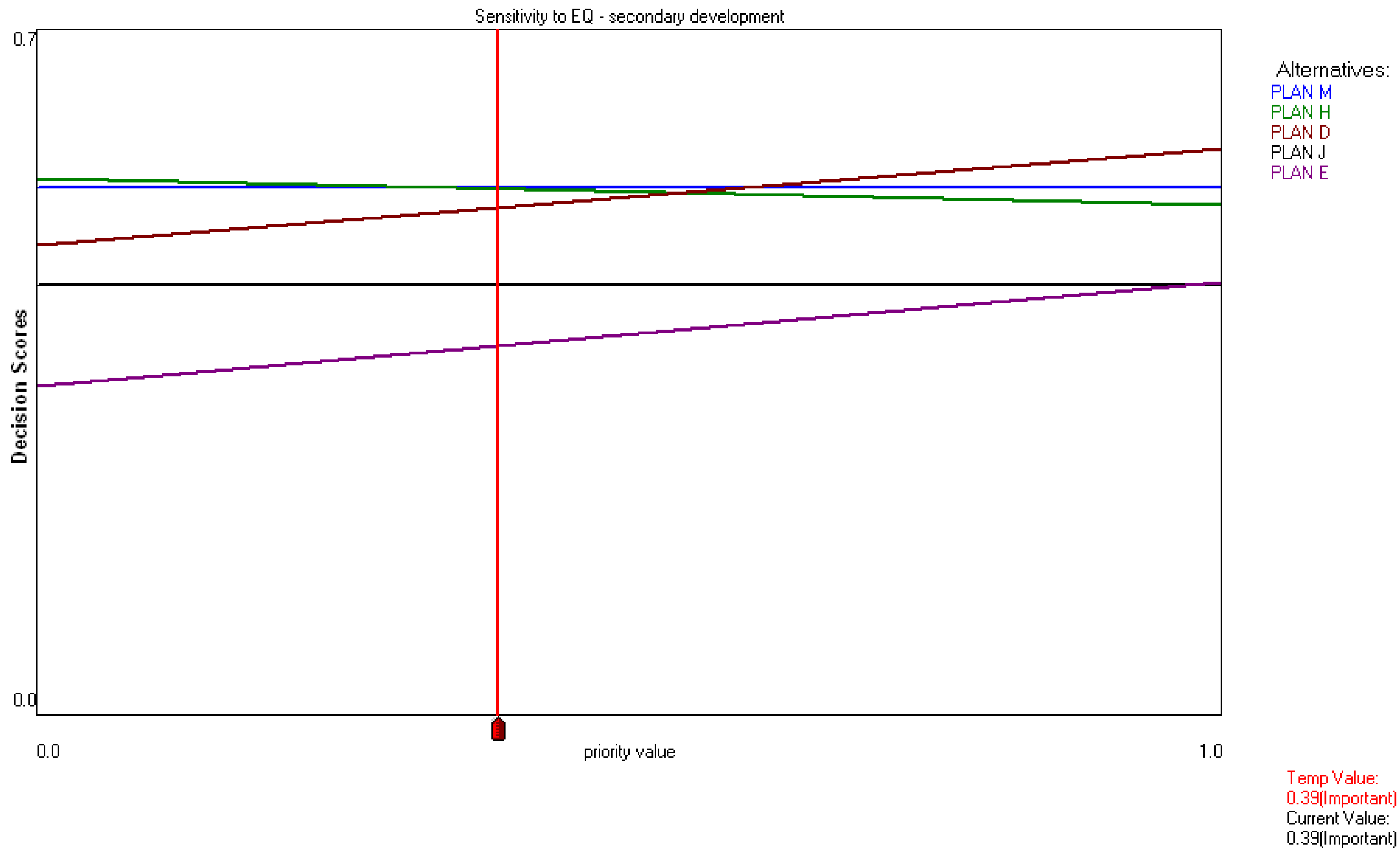

Figure 6A. Sensitivity of decision scores to EQ: Secondary Development based on Collaboration Team's weights.

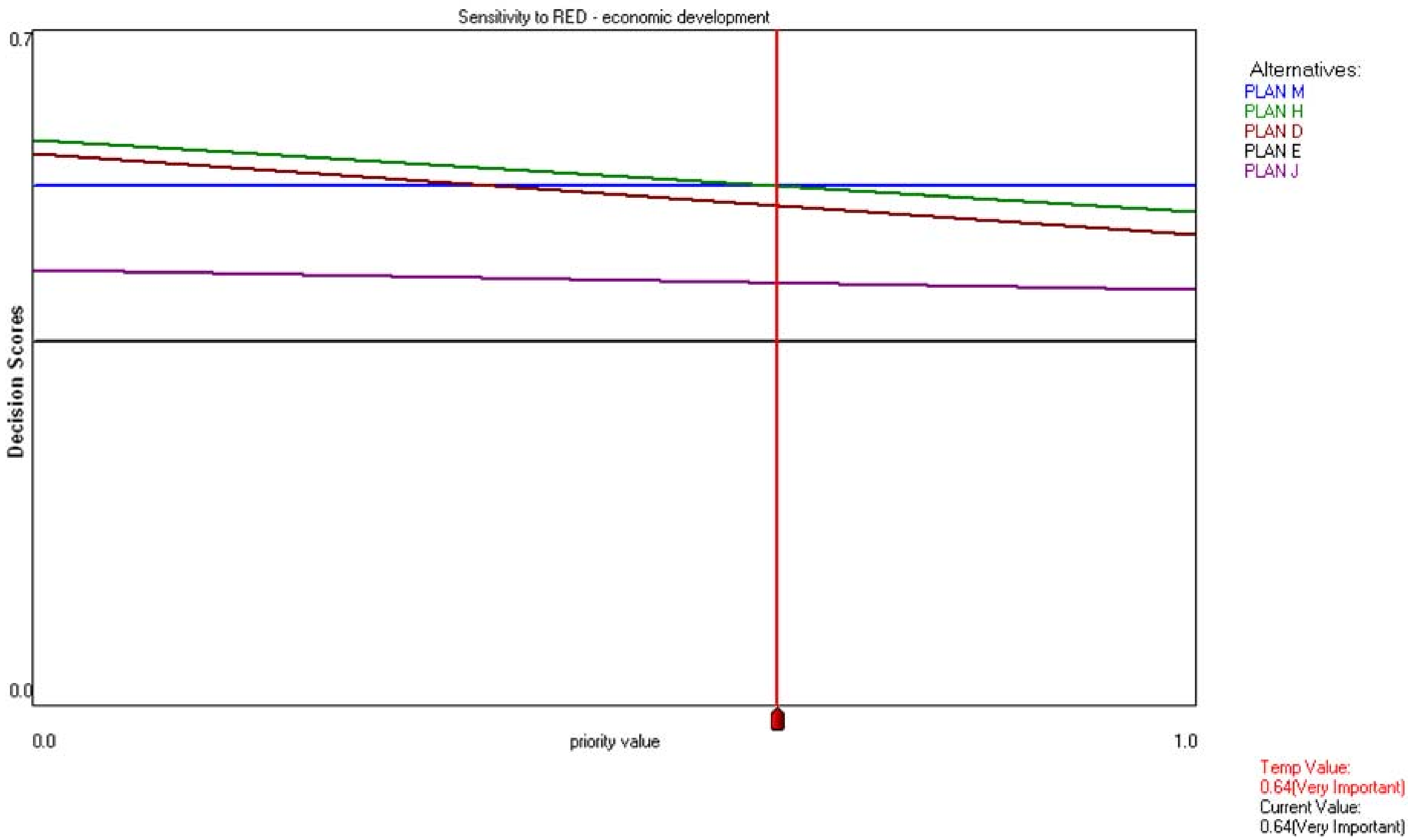

Figure 7A. Sensitivity of decision scores to RED: Economic Development based on Collaboration Team's weights.

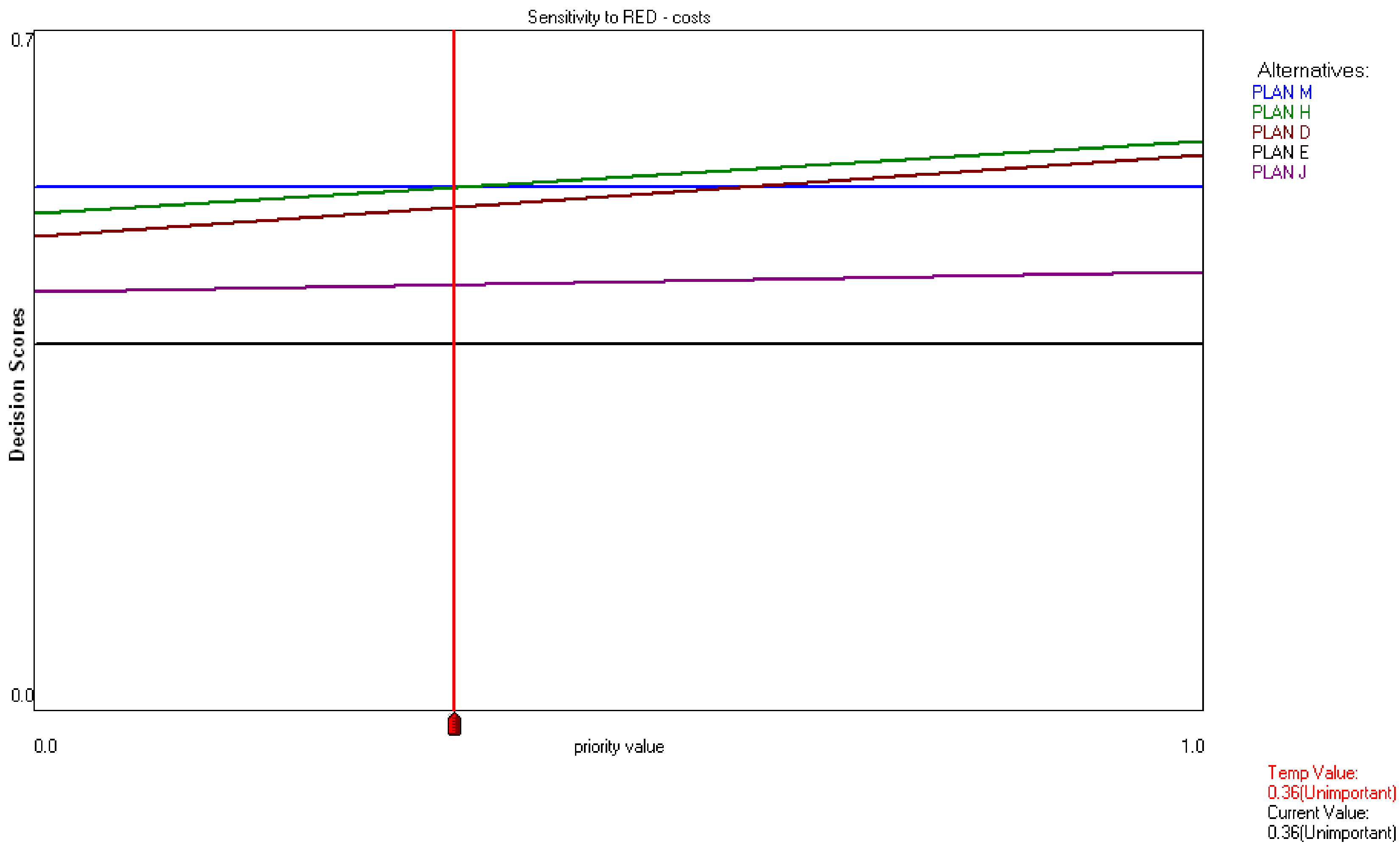

Figure 8A. Sensitivity of decision scores to RED: Cost based on Collaboration Team's weights.

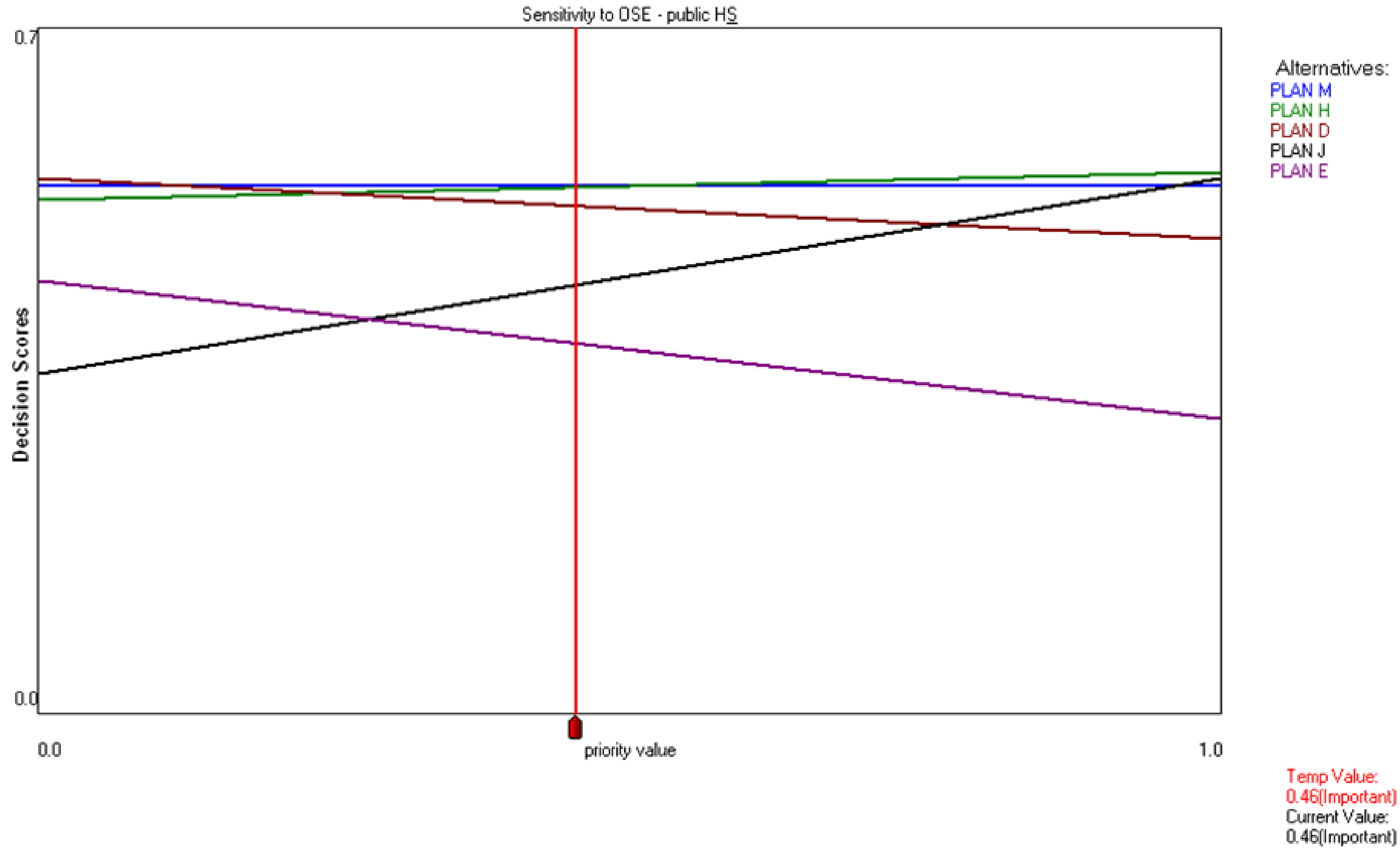

Figure 9A. Sensitivity of decision scores to OSE: Public Health and Safety based on Collaboration Team's weights.

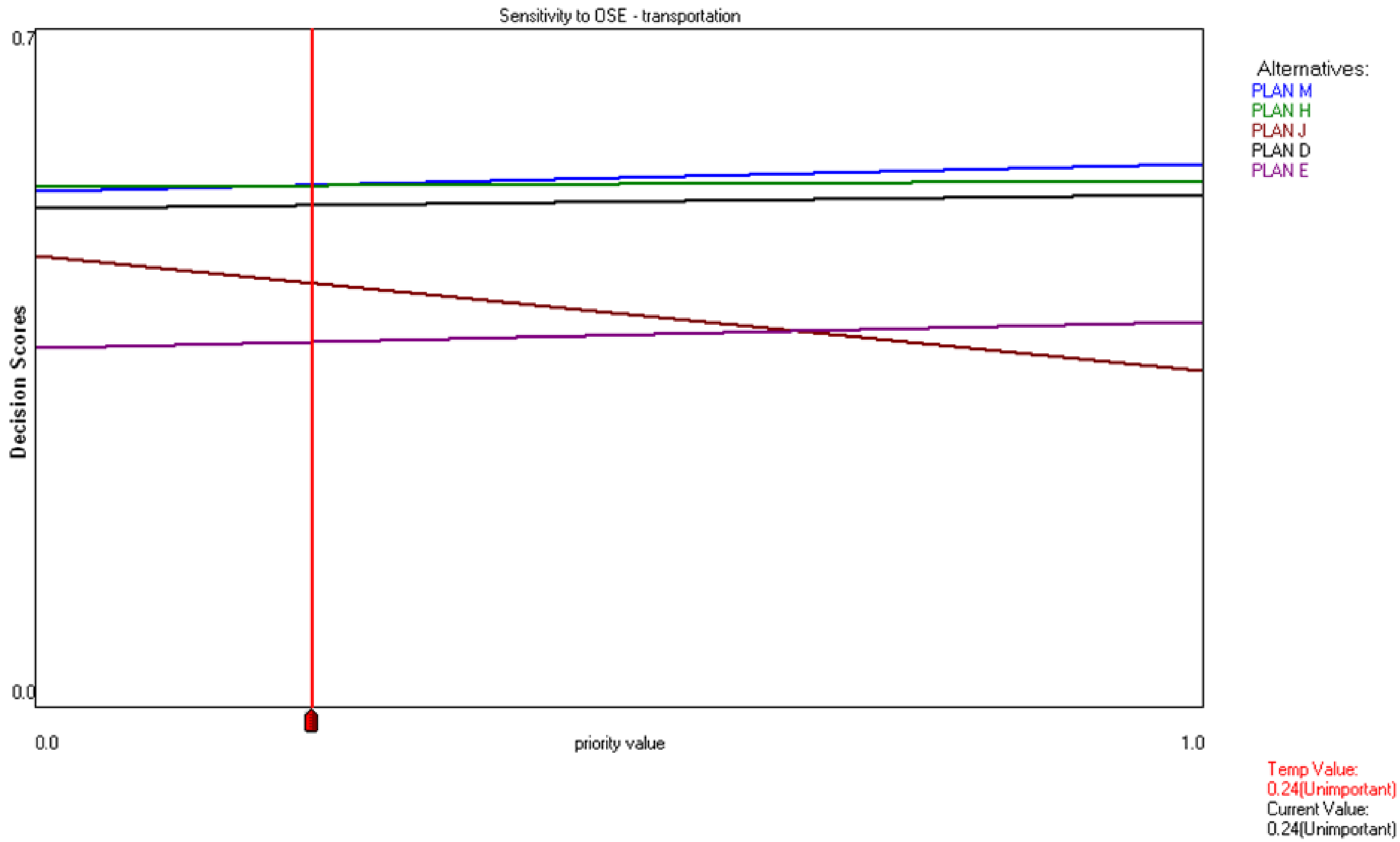

Figure 10A. Sensitivity of decision scores to OSE: Transportation based on Collaboration Team's weights.

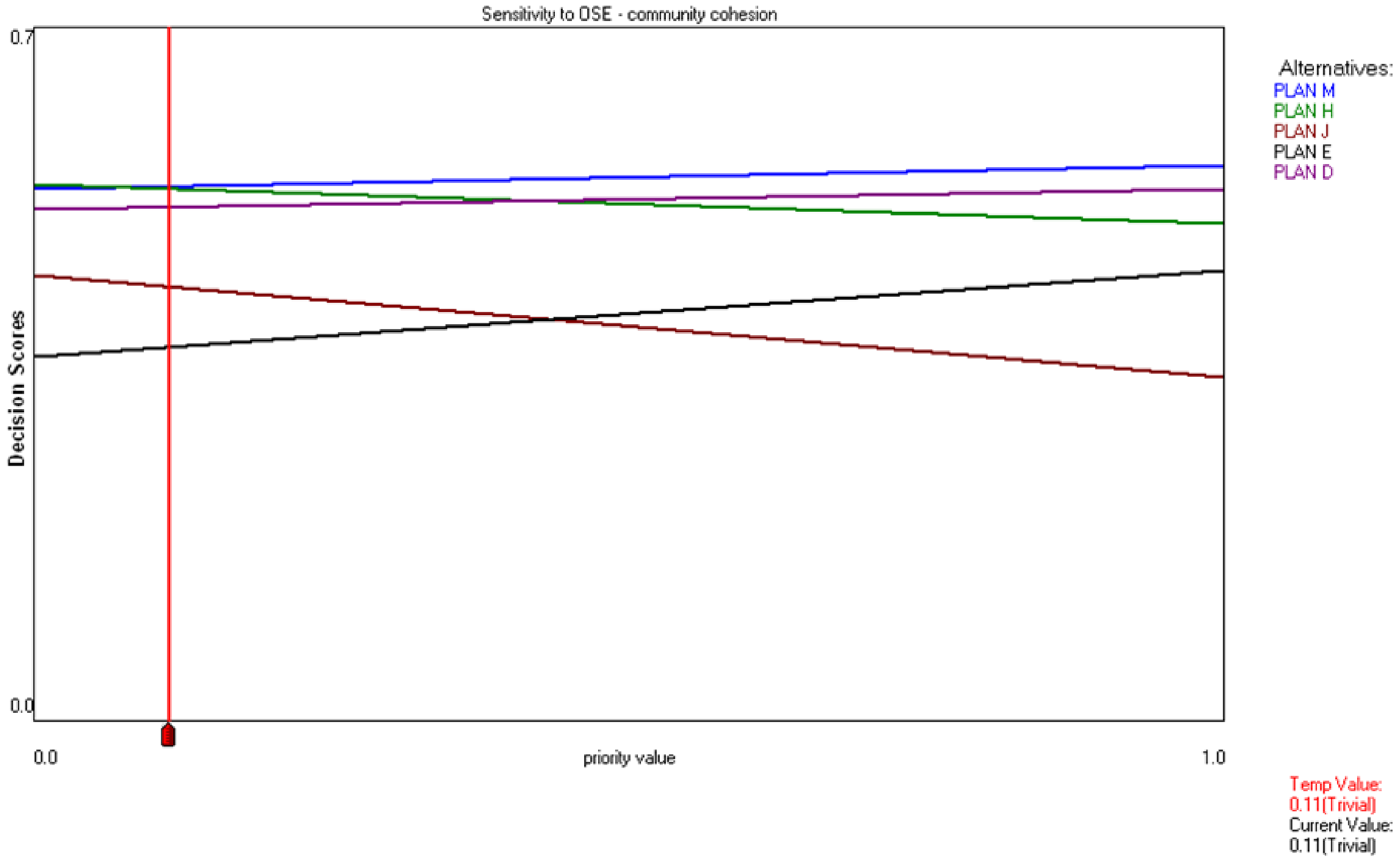

Figure 11A. Sensitivity of decision scores to OSE: Community Cohesion based on Collaboration Team's weights.

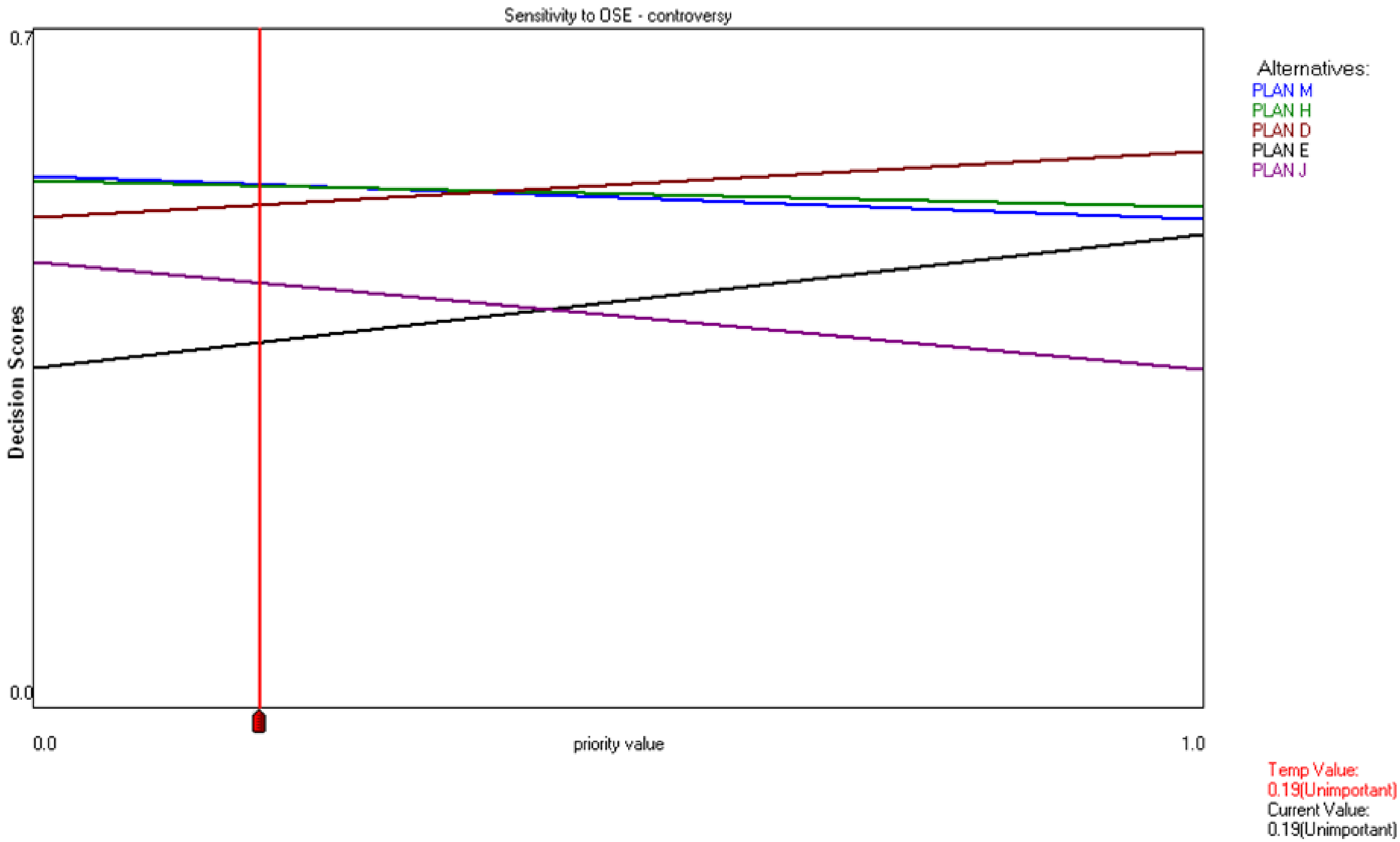

Figure 12A. Sensitivity of decision scores to OSE: Controversy based on Collaboration Team's weights.

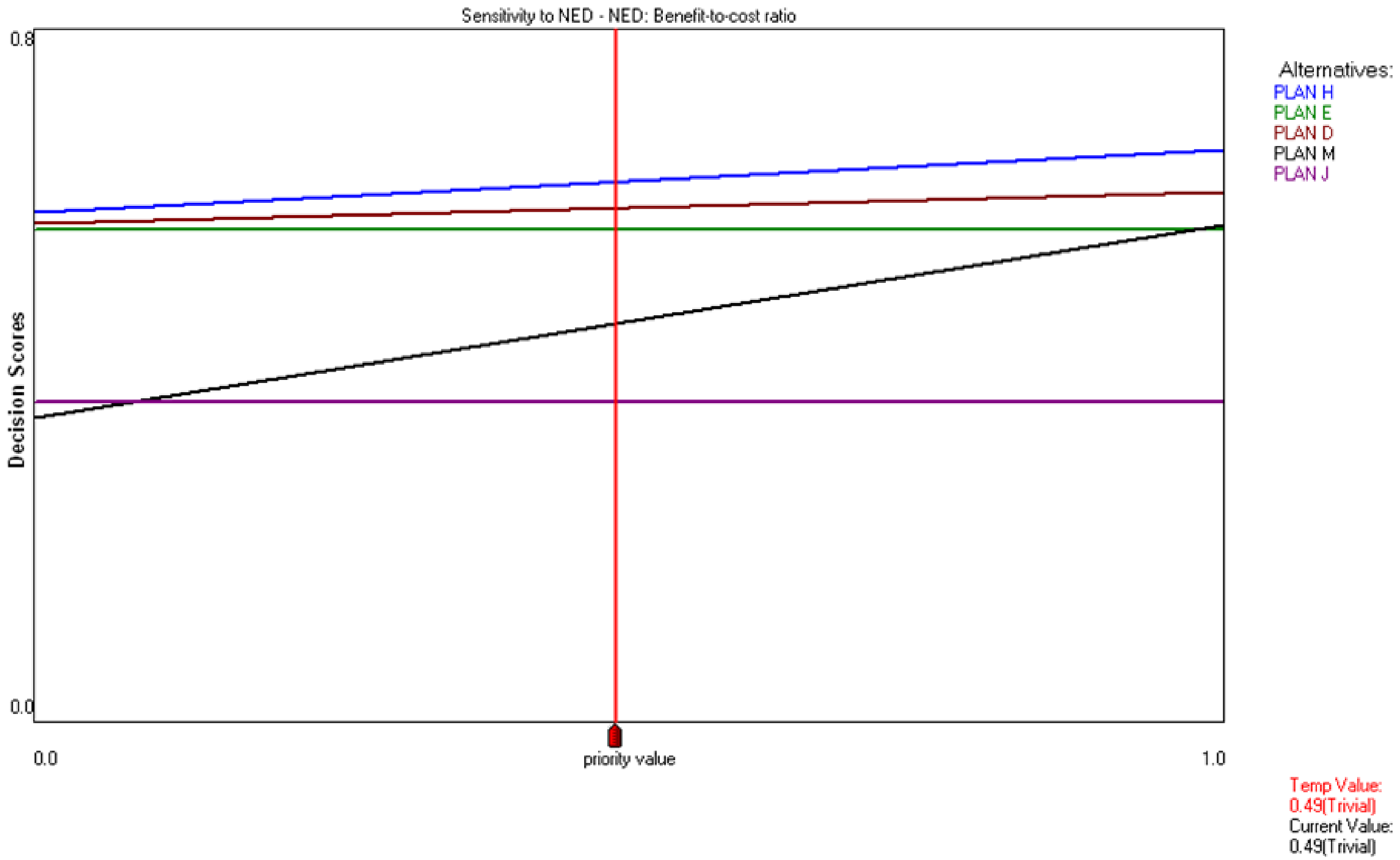

Figure 13A. Sensitivity of decision scores to NED: Benefit-to-Cost Ratio based on Corps Team's weights.

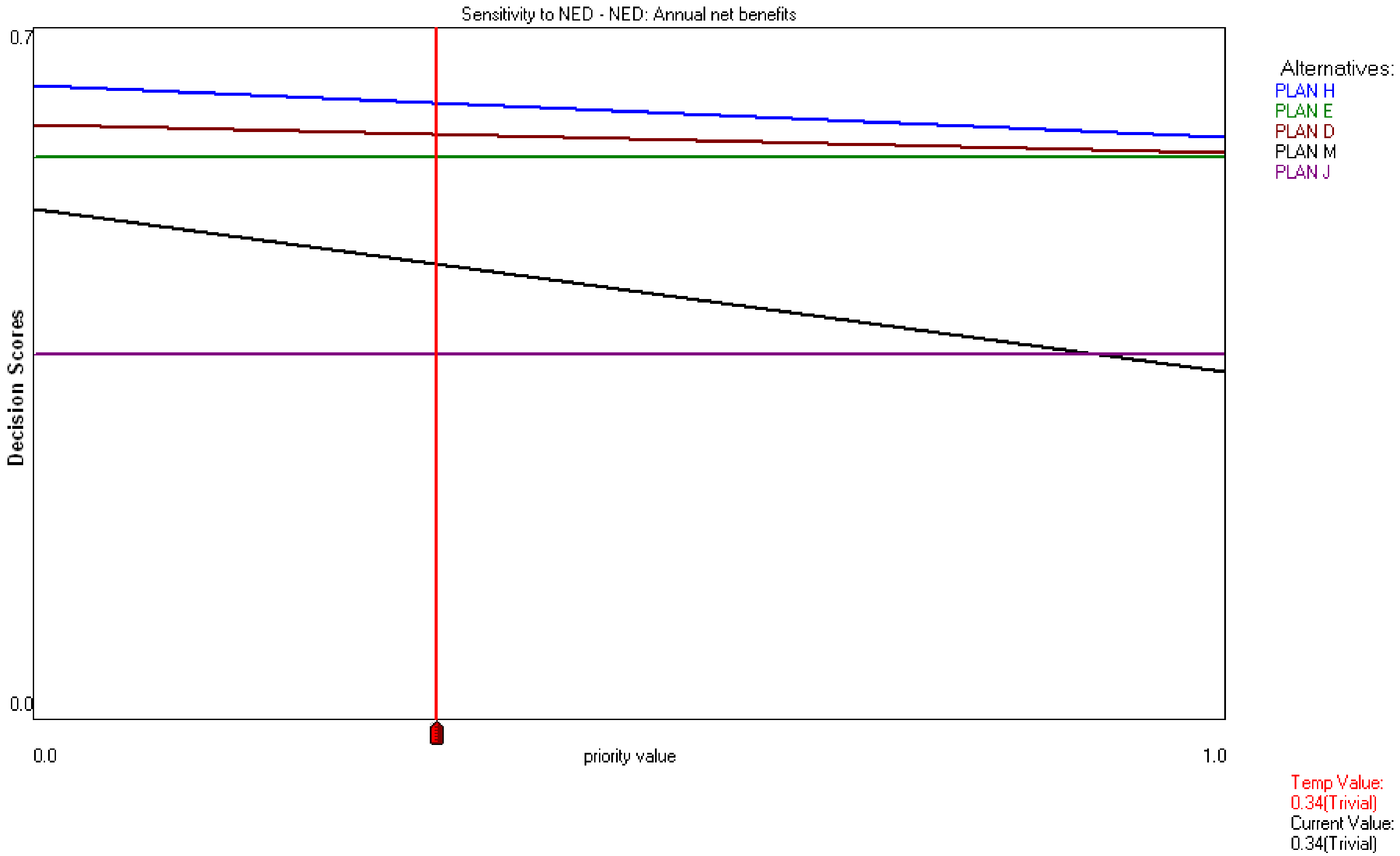

Figure 14A. Sensitivity of decision scores to NED: Annual Net Benefits based on Corps Team's weights.

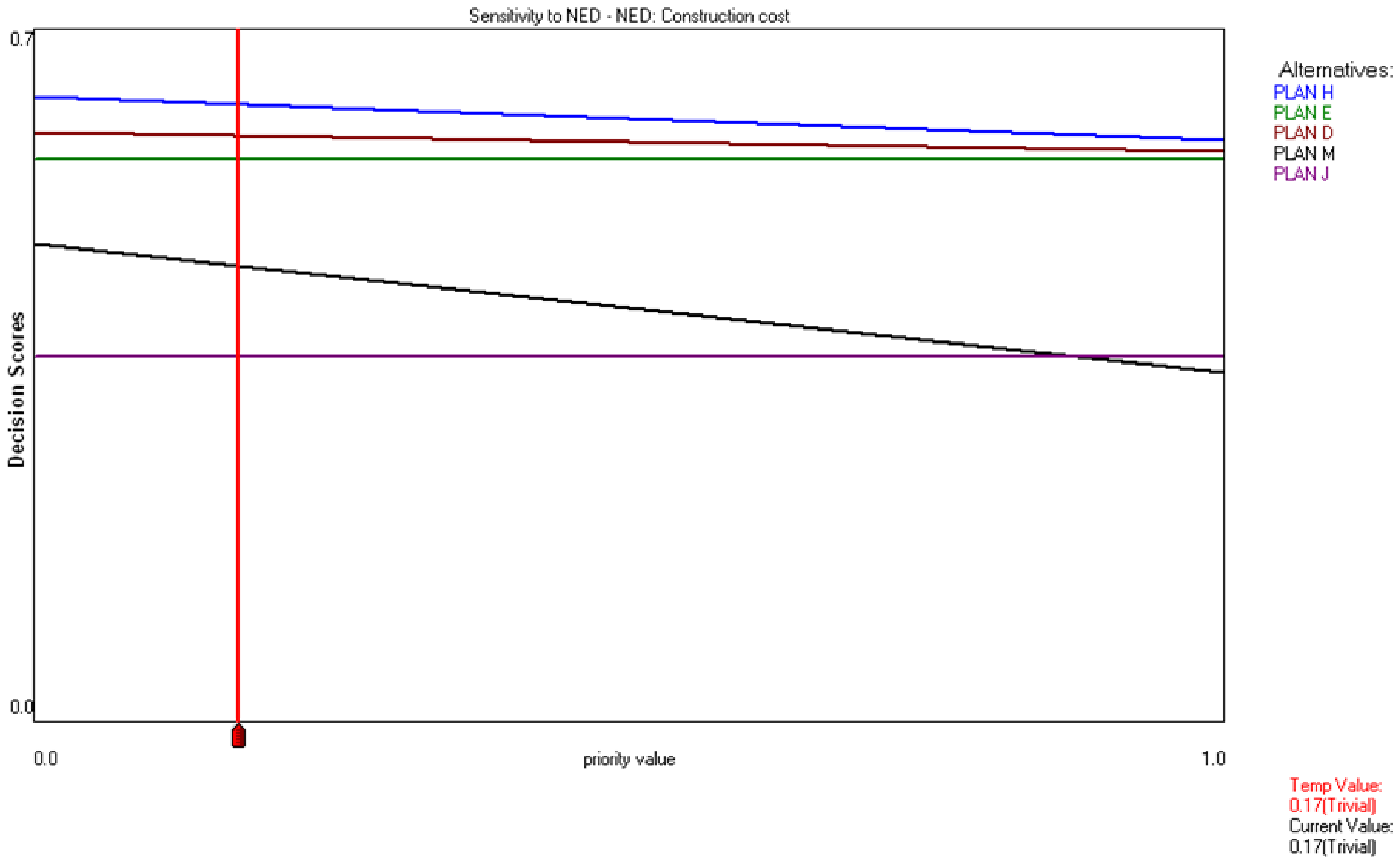

Figure 15A. Sensitivity of decision scores to NED: Construction Cost based on Corps Team's weights.

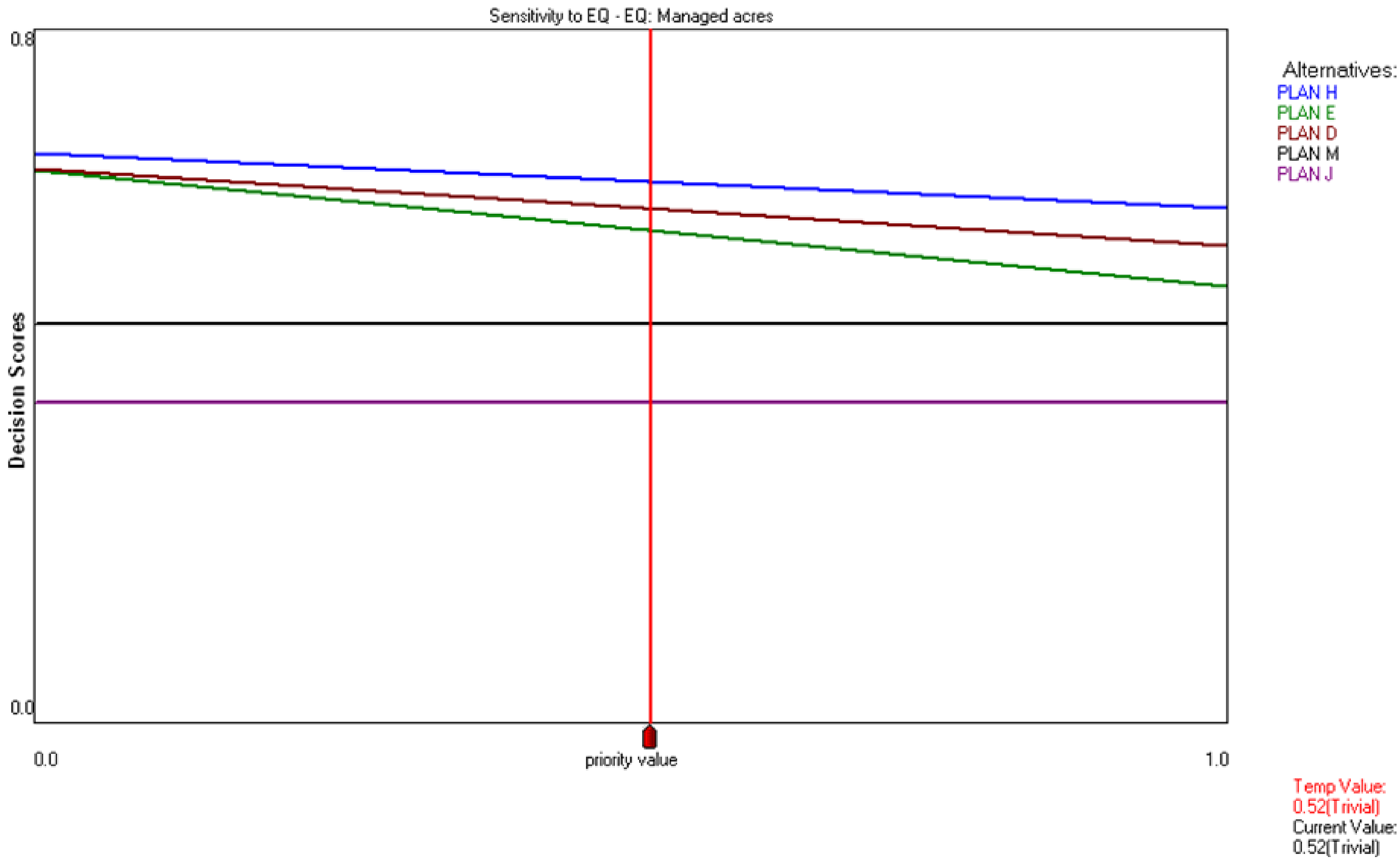

Figure 16A. Sensitivity of decision scores to EQ: Managed Acres based on Corps Team's weights.

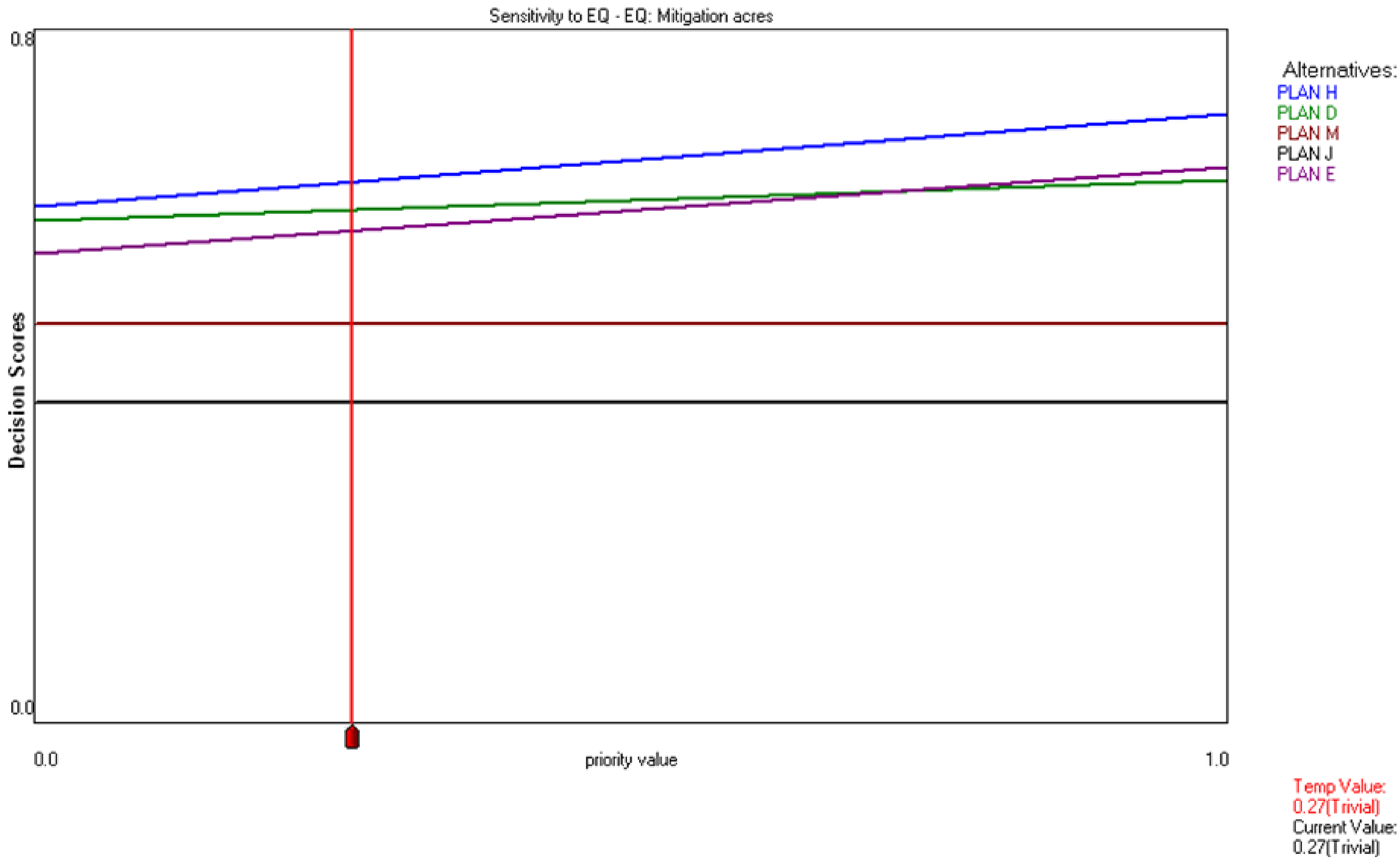

Figure 17A. Sensitivity of decision scores to EQ: Mitigation Acres based on Corps Team's weights.

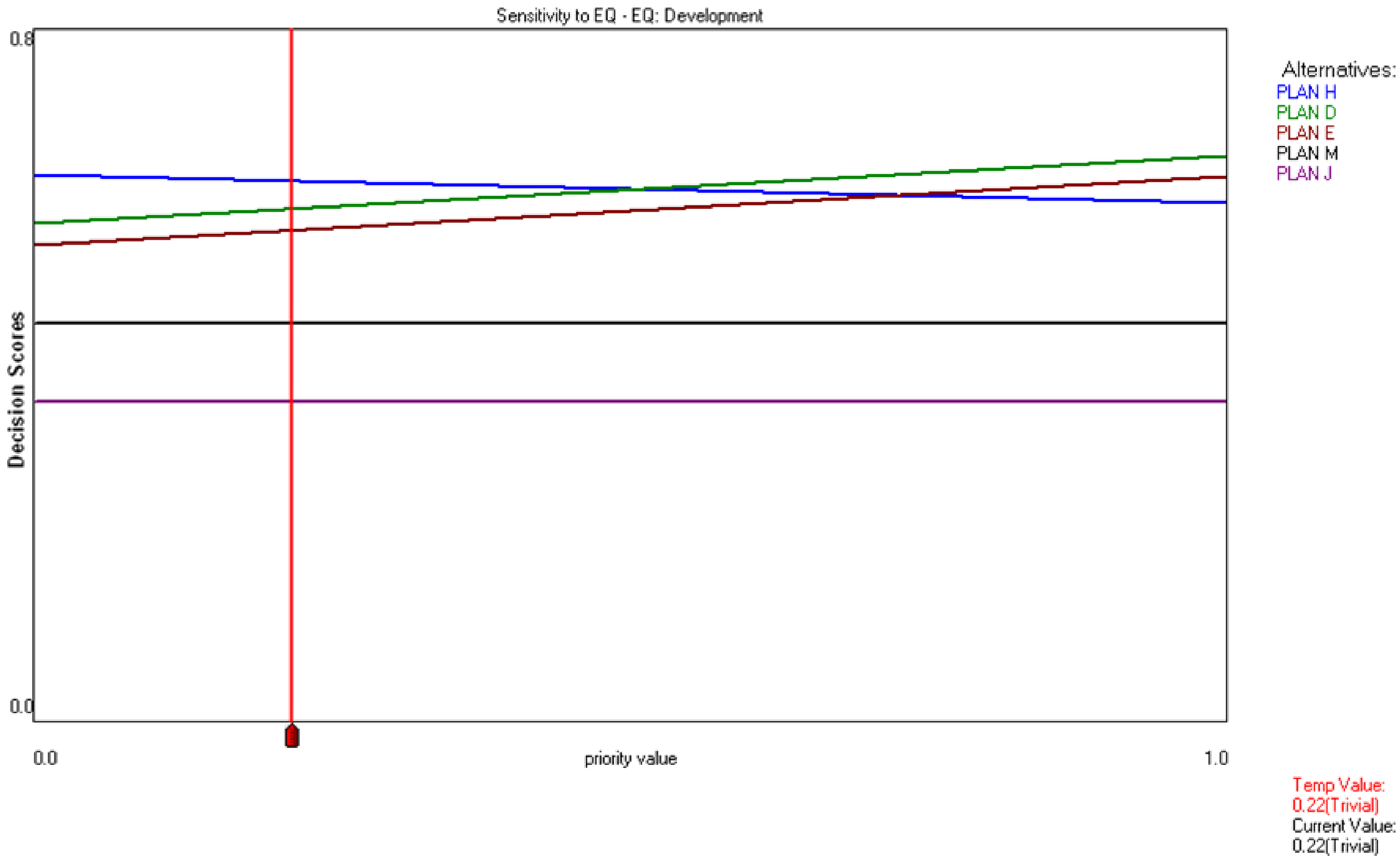

Figure 18A. Sensitivity of decision scores to EQ: Secondary Development based on Corps Team's weights.

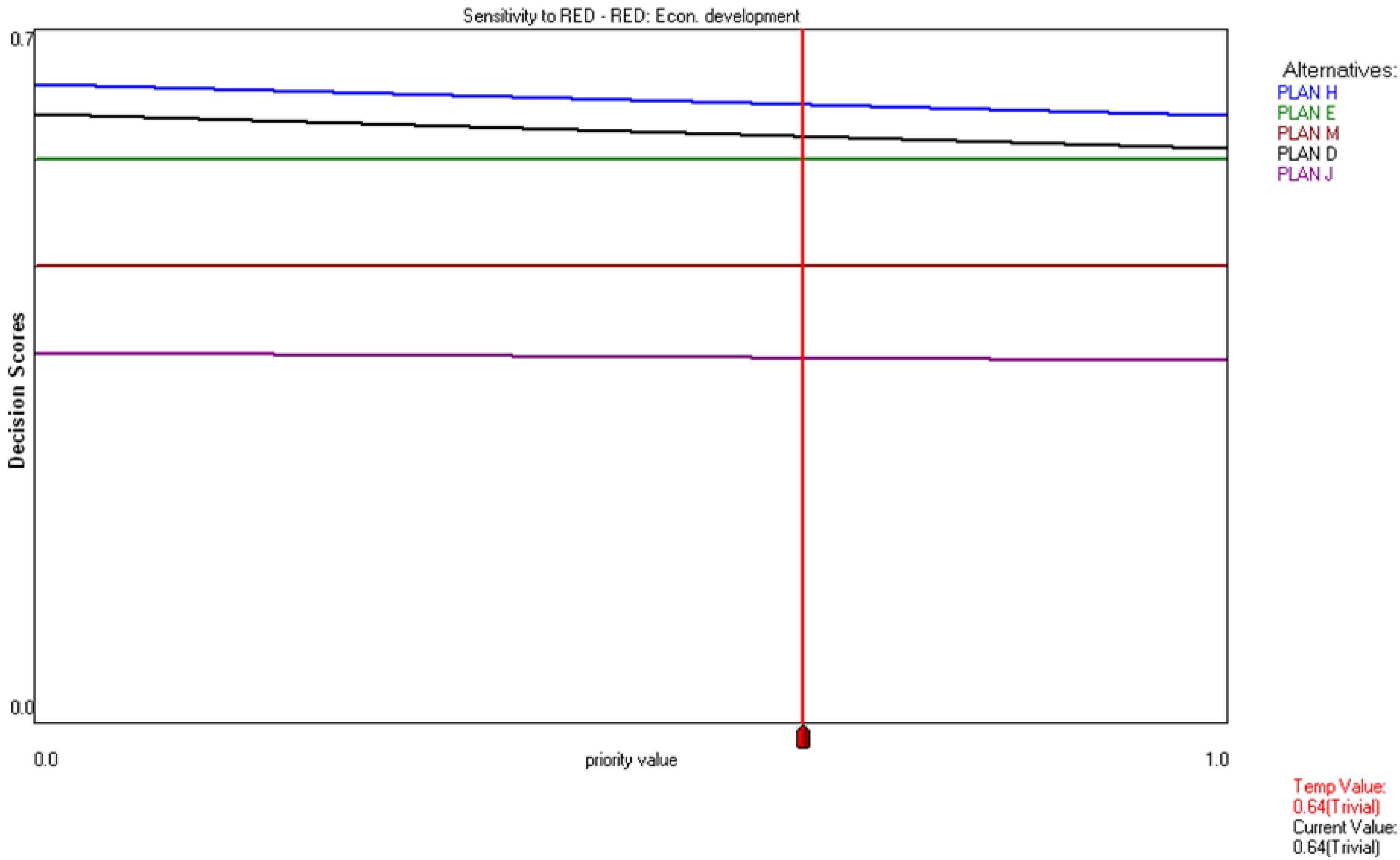

Figure 19A. Sensitivity of decision scores to RED: Economic Development based on Corps Team's weights.

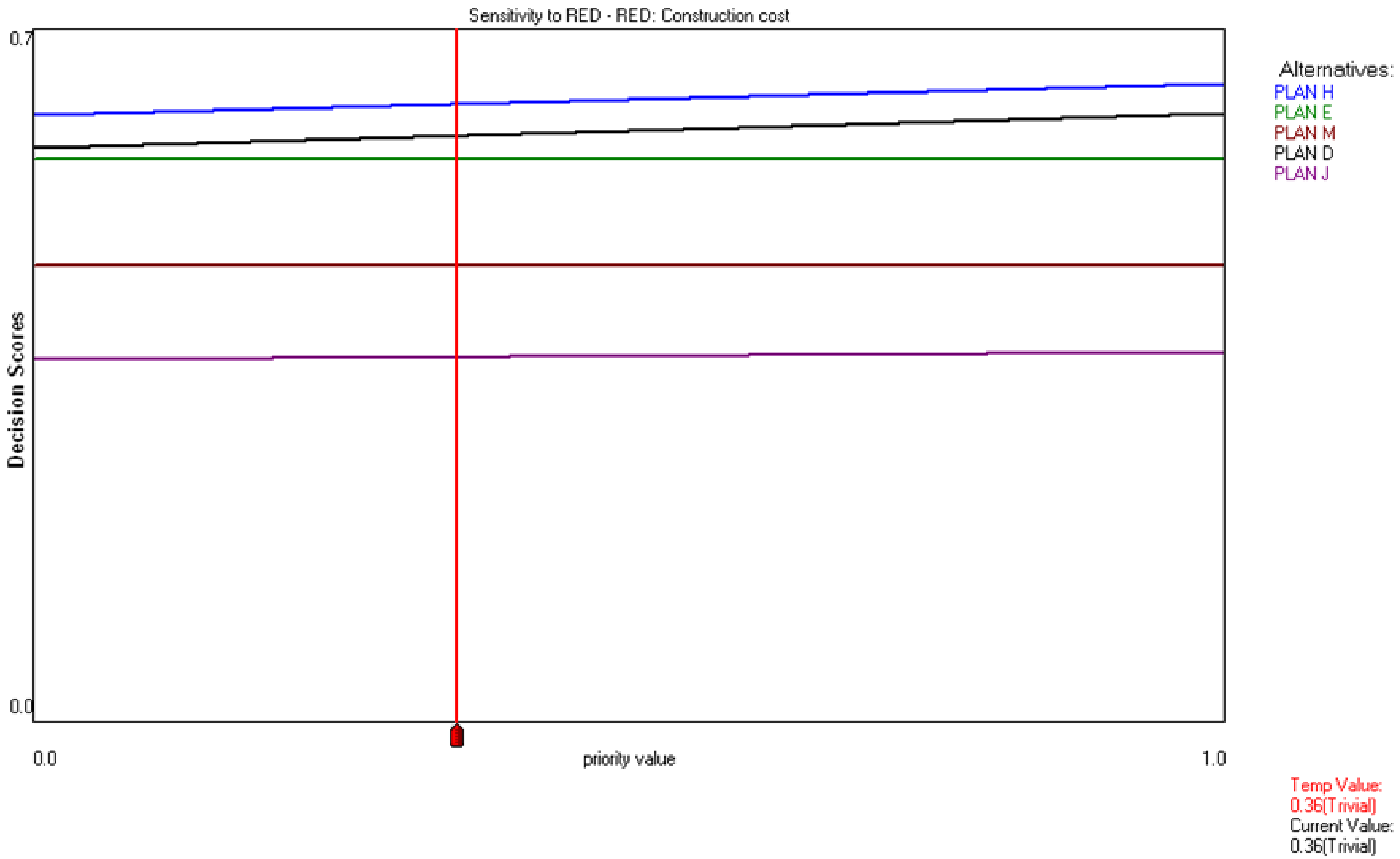

Figure 20A. Sensitivity of decision scores to RED: Construction Cost based on Corps Team's weights.

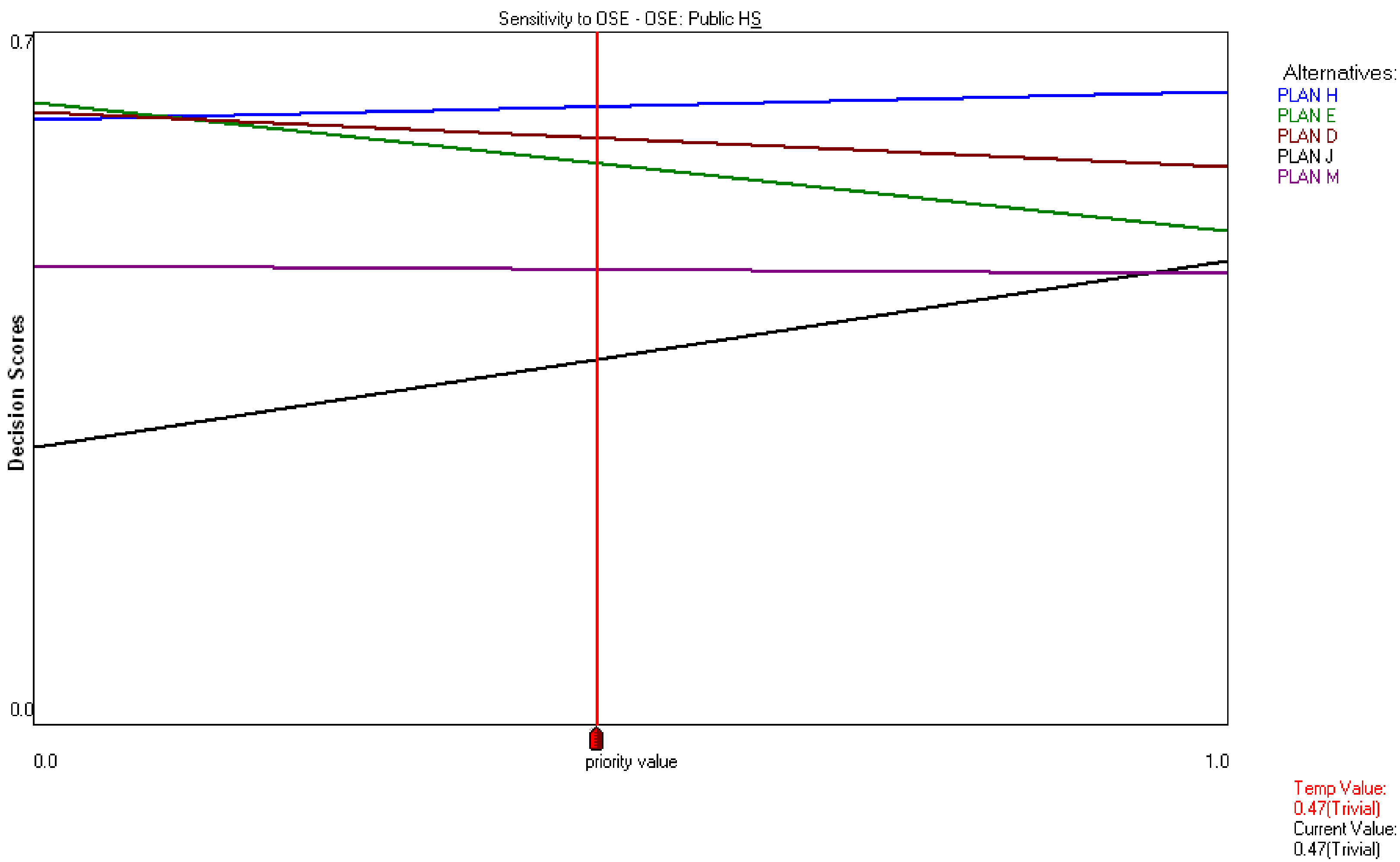

Figure 21A. Sensitivity of decision scores to OSE: Public Health and Safety based on Corps Team's weights.

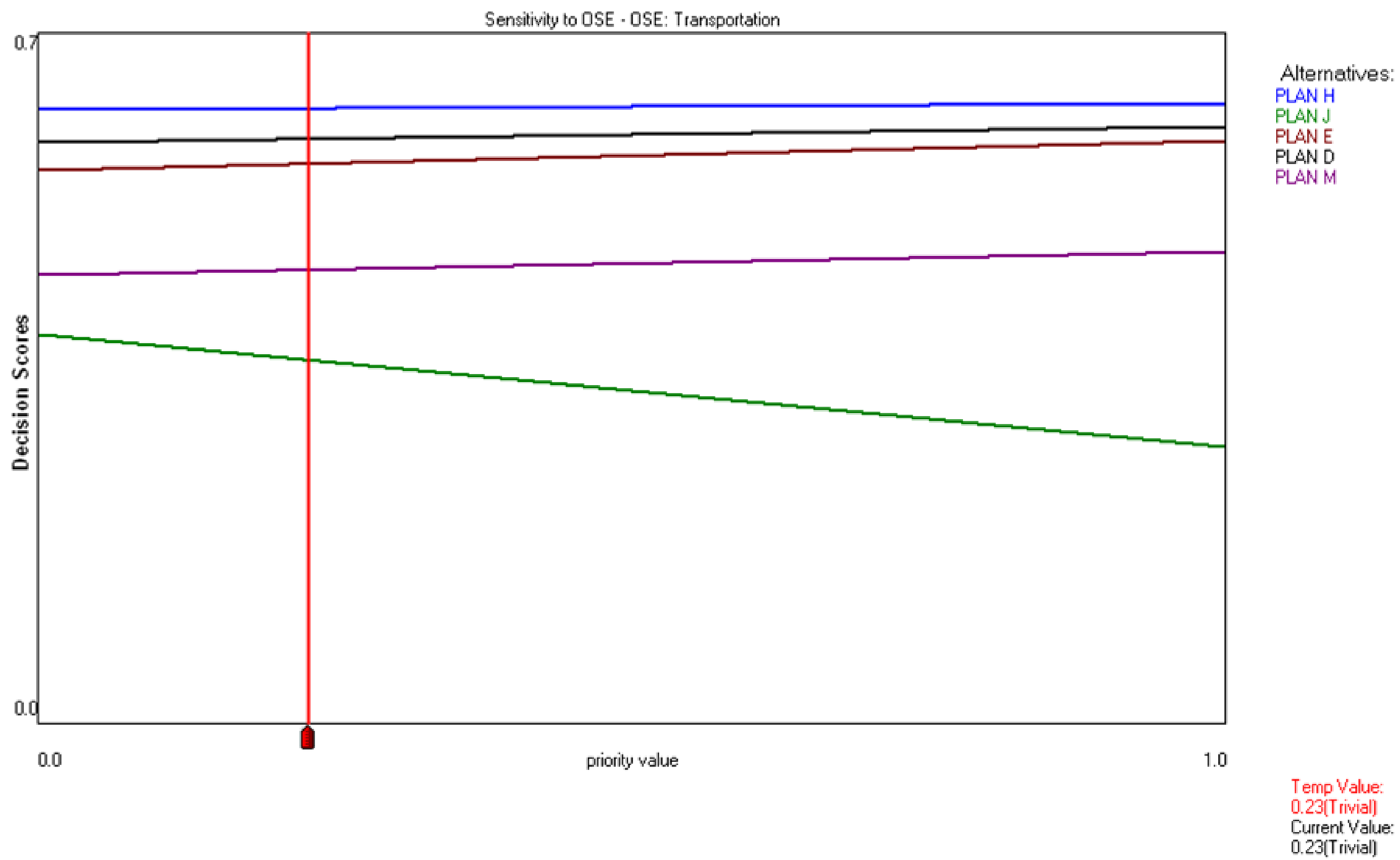

Figure 22A. Sensitivity of decision scores to OSE: Transportation based on Corps Team's weights.

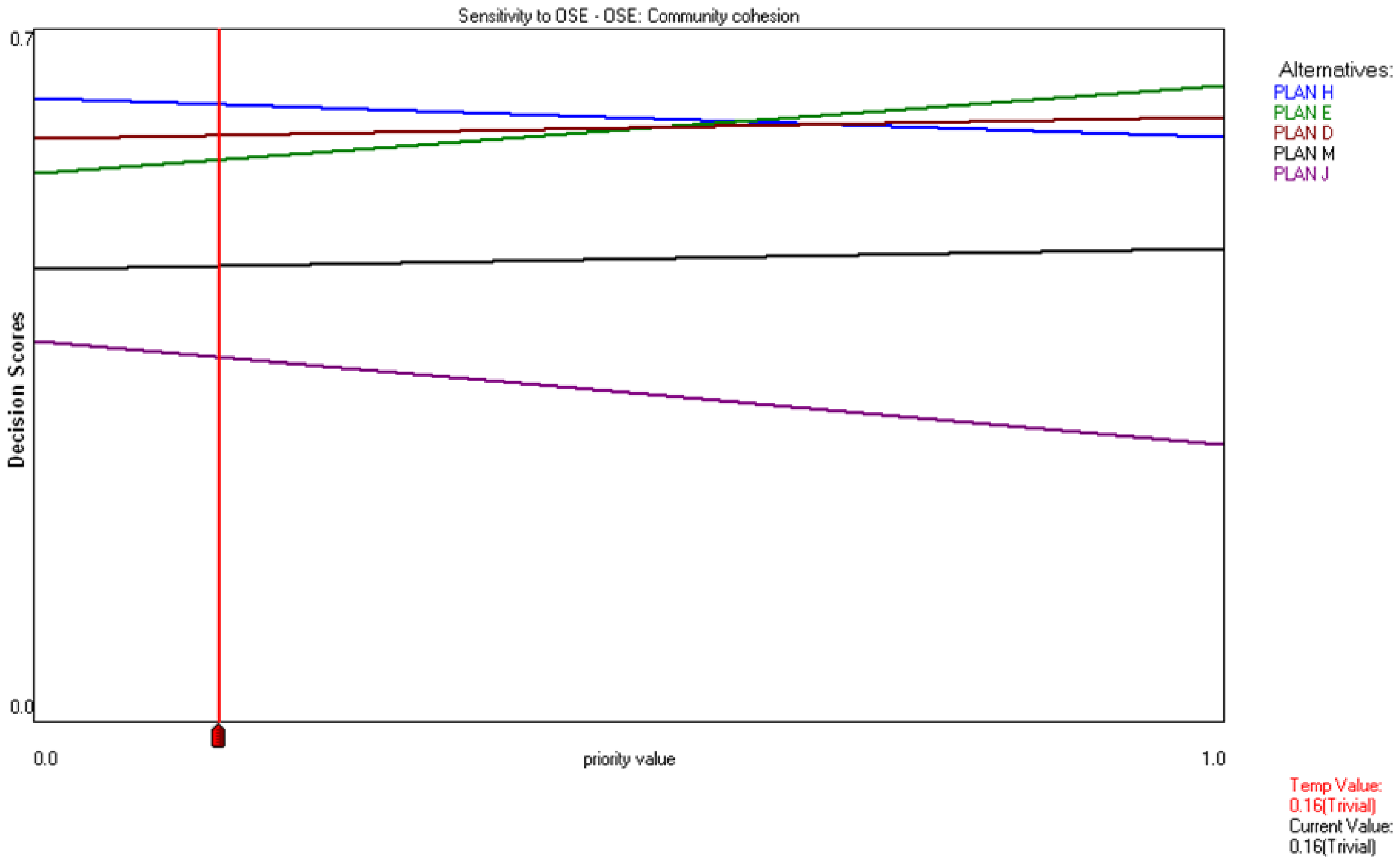

Figure 23A. Sensitivity of decision scores to OSE: Community Cohesion based on Corps Team's weights.

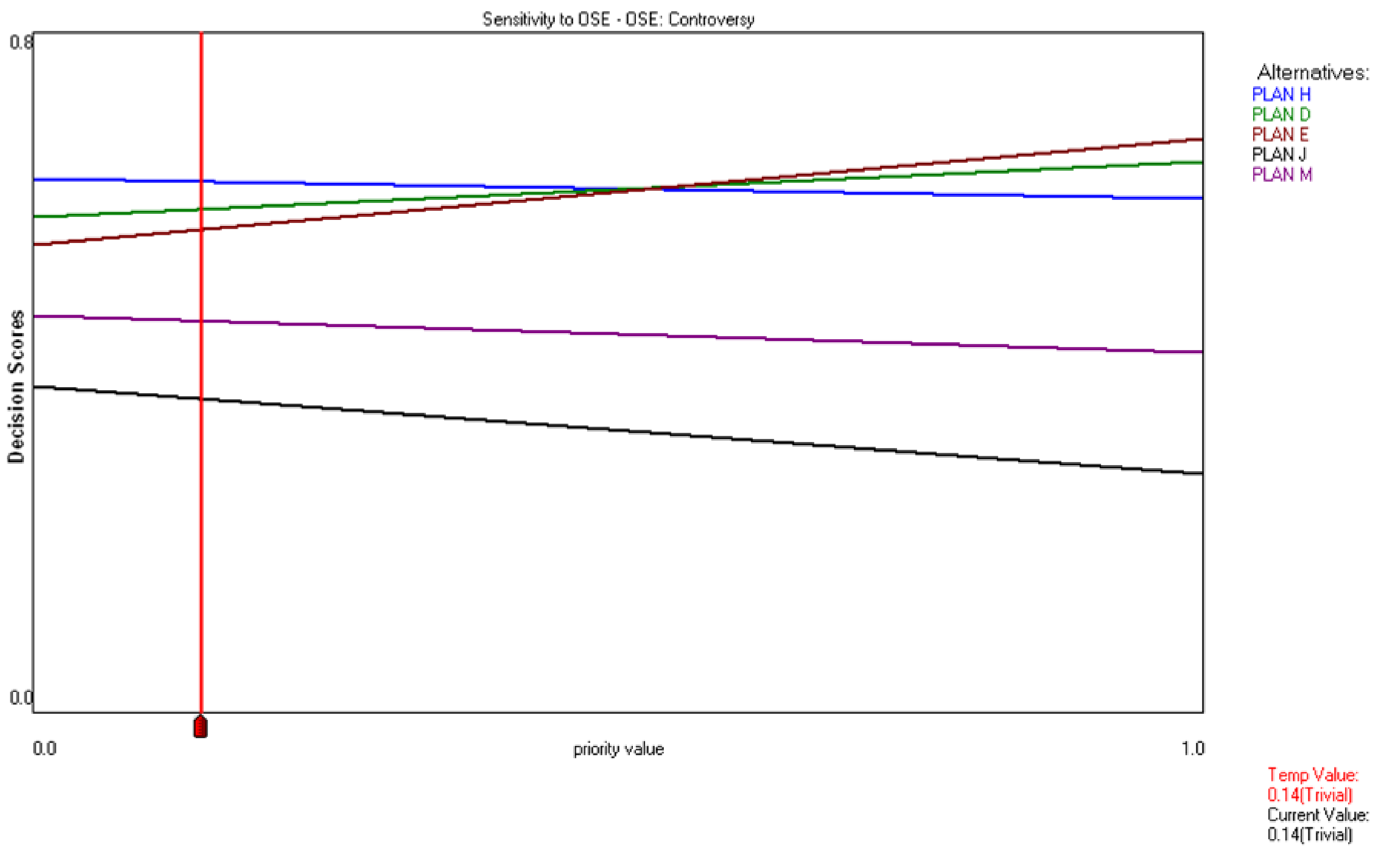

Figure 24A. Sensitivity of decision scores to OSE: Controversy based on Corps Team's weights.