

# The Art of the Trade Study



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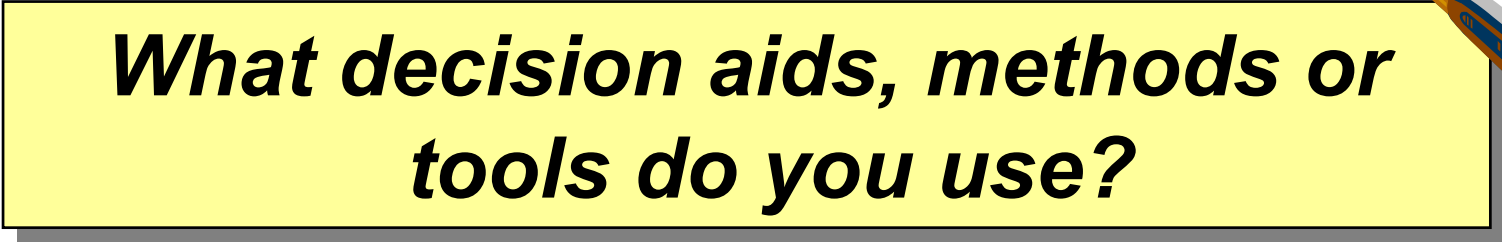
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# My Purpose Today

- Explain the value of a defined methodology for conducting engineering trades
- Describe a proven trade study process
- Explain how the Analytical Hierarchy Process (AHP) methodology can be applied to your trade studies

How are your trade study decisions typically made?

BOGGSAT?



*What decision aids, methods or tools do you use?*

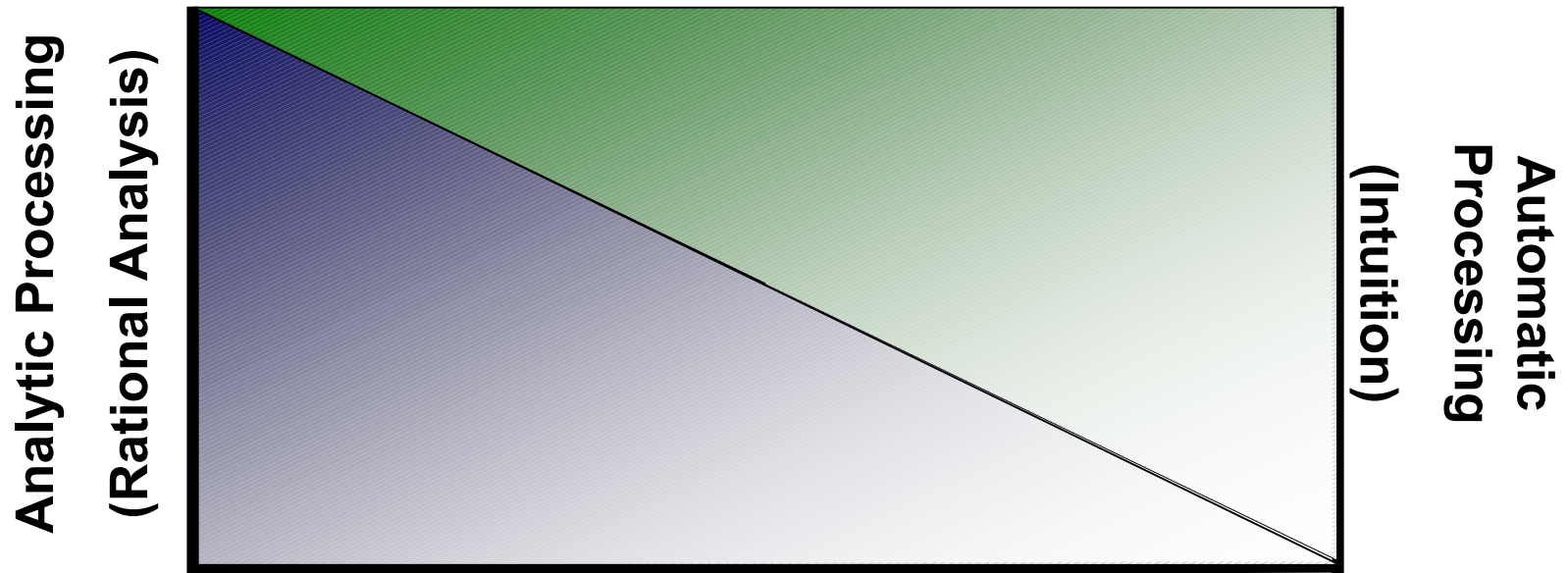
# Context

- Systems Engineers constantly define, prioritize, and decide programmatic, technical and life cycle concerns
- Proper technical decision making must balance:
  - Performance
  - Cost effectiveness
  - Schedule
  - Reliability, Maintainability, & Supportability
- The Trade Study is a core SE skill
  - Provides a repeatable, efficient method for visible, traceable, justifiable, decisions

**What obstacles to effective trade studies do you encounter on your project (s)?**



# How do engineers really make decisions?



*How often do you use your intuition to make engineering decisions?*

# Intuition Test

According to research at an English university, it doesn't matter in what order the letters in a word are, only that the first and last letters are at the right places. The rest can be a total mess and you can still read it without a problem. This is because we do not read every letter by itself, but the word as a whole.

# The Trouble with Intuition

- Common Cognitive Biases in Engineering Decisions
  - Group Think
  - Status Quo Bias
  - Overconfidence Bias
  - Wishful Thinking Errors
  - Input Bias
  - Confirming Evidence Bias

## Common Effects:

- Failure to critically examine all alternatives
- Tendency to continue to "do things the way we we've done them."
- Illusion of control over stochastic events
- Overestimation of probability of desired outcomes

# The Case for a Consistent Trade Study Methodology

- Provides a better *expected* outcome than random choice
  - We can't control outcomes; the best we can do is influence the probability of certain outcomes
- Overcome cognitive biases
  - Mitigate negative effects of intuition
- Permits decision traceability
  - Allows decision process improvement
- Builds justification and helps others understand reasoning
  - More likely to influence up the management chain

*As I think back over the years, I have been guided by four principles in decision making. First, the only certainty is that there is no certainty. Second, every decision, as a consequence, is a matter of weighing probabilities. Third, despite uncertainty we must decide and we must act. And lastly, we need to judge decisions not only the results but on how they were made.*

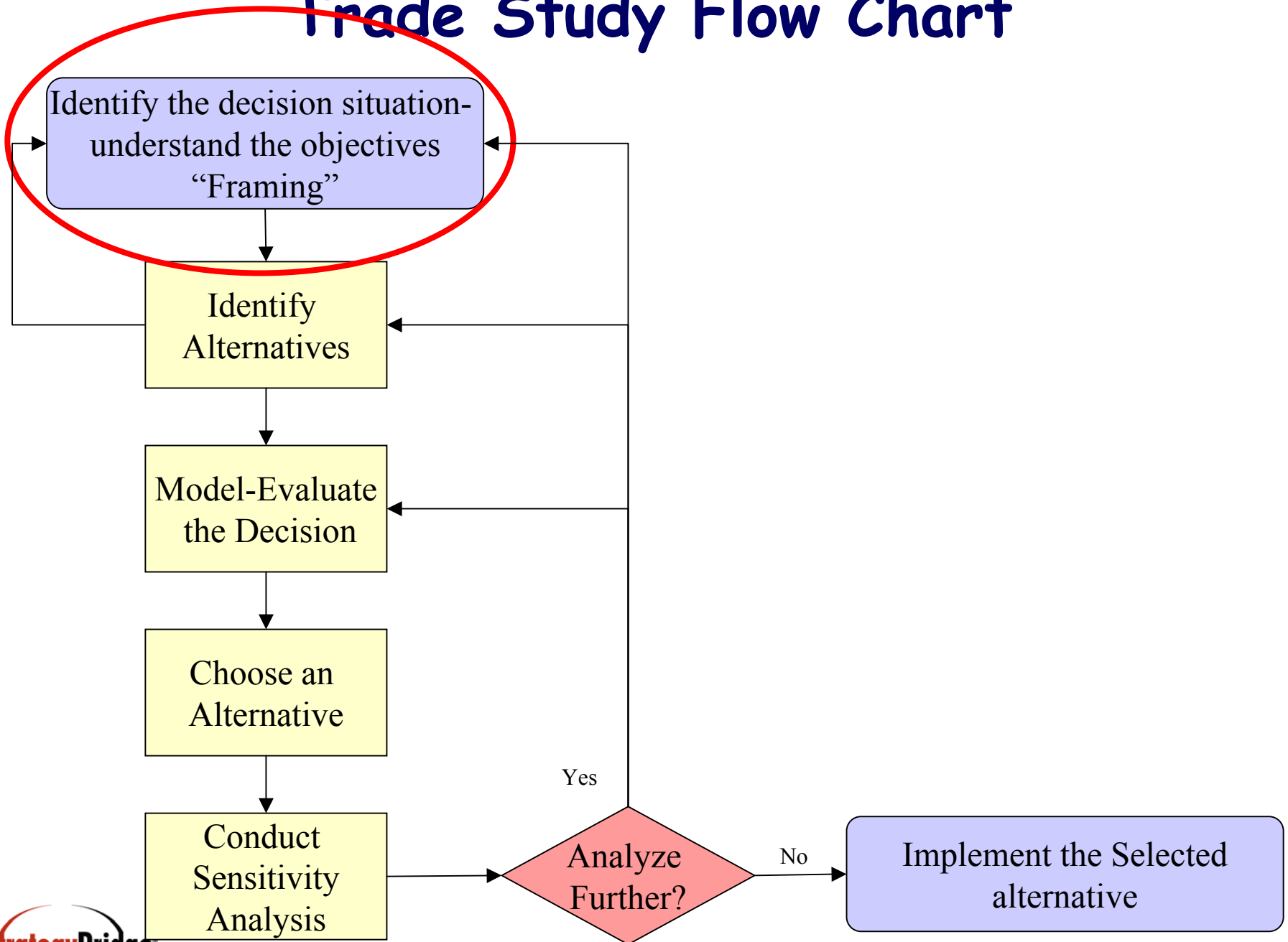
Robert Rubin, 1999

# Purpose of a Structured Trade Study

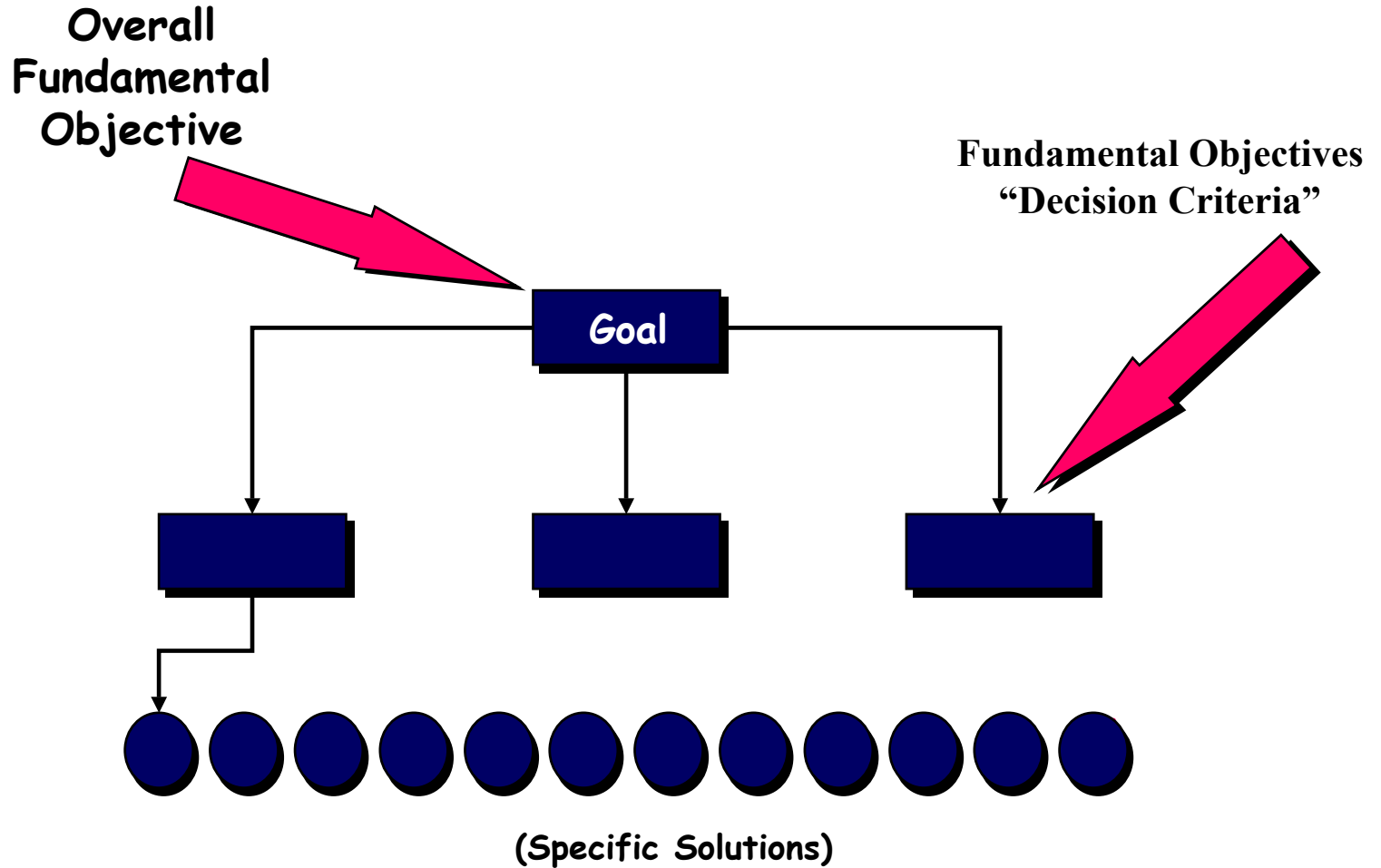
- Reach the right decision for the right reasons
  - Don't settle for just *any* decision because your team is too exhausted to argue any longer

***Making tradeoffs is a fact of organizational life, especially in a resource-constrained environment. ...priorities must be determined on the basis of the enterprise's overall objectives.***

# Trade Study Flow Chart



# Understanding Your Frame



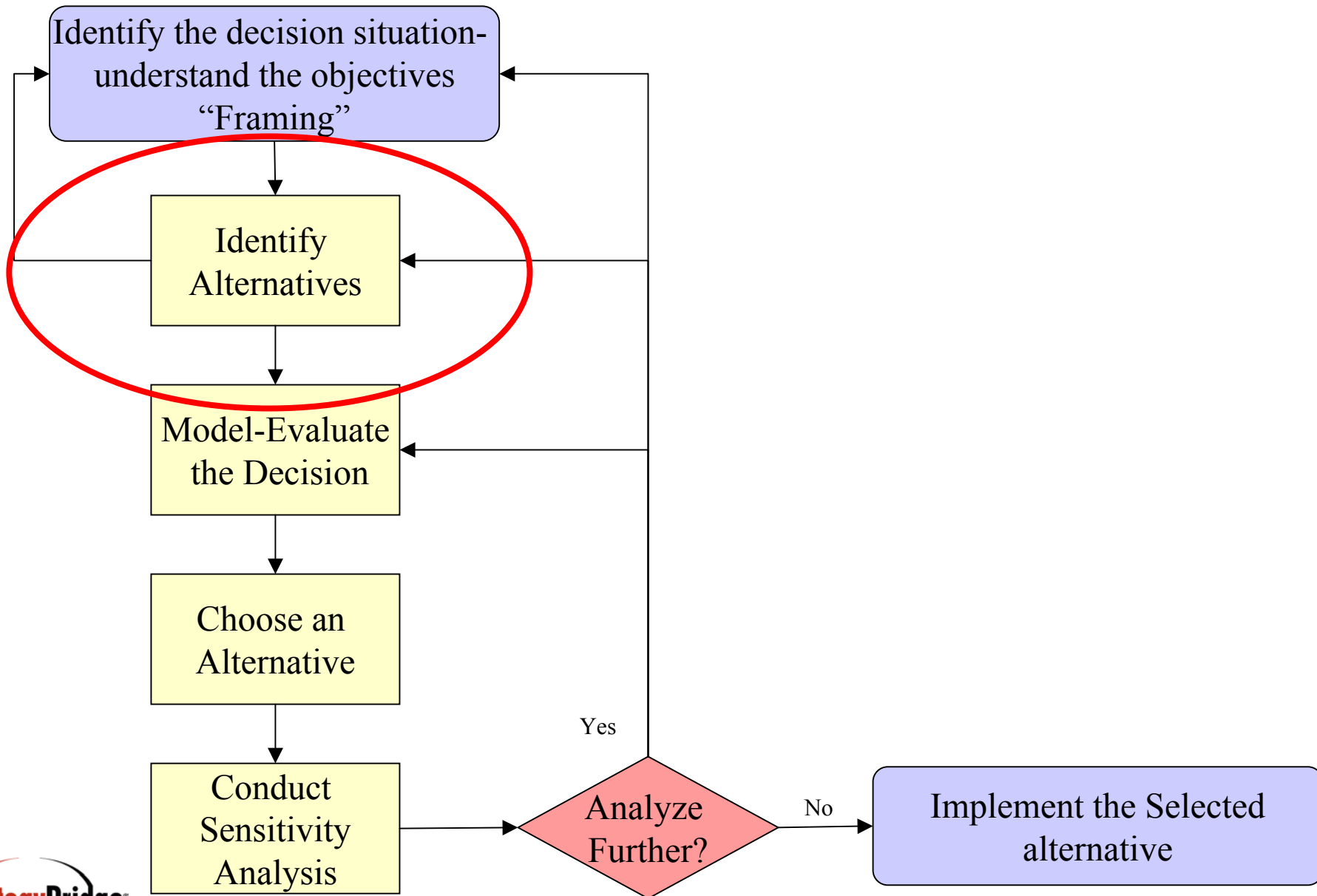
# Culture and Risk Philosophy are crucial to the decision frame

- Abstract ideas that influence thinking and action in the organization
- Behaviors that are celebrated or rewarded reflect true values

## Context of Implementation will Drive:

- Design
- Design Margin
- Reliability
- Quality

# Trade Study Flow Chart



# Generating Alternatives

**“Alternatives are the raw material of decision making”**

*-Smart Choices by Hammond, Keeney & Raiffa*

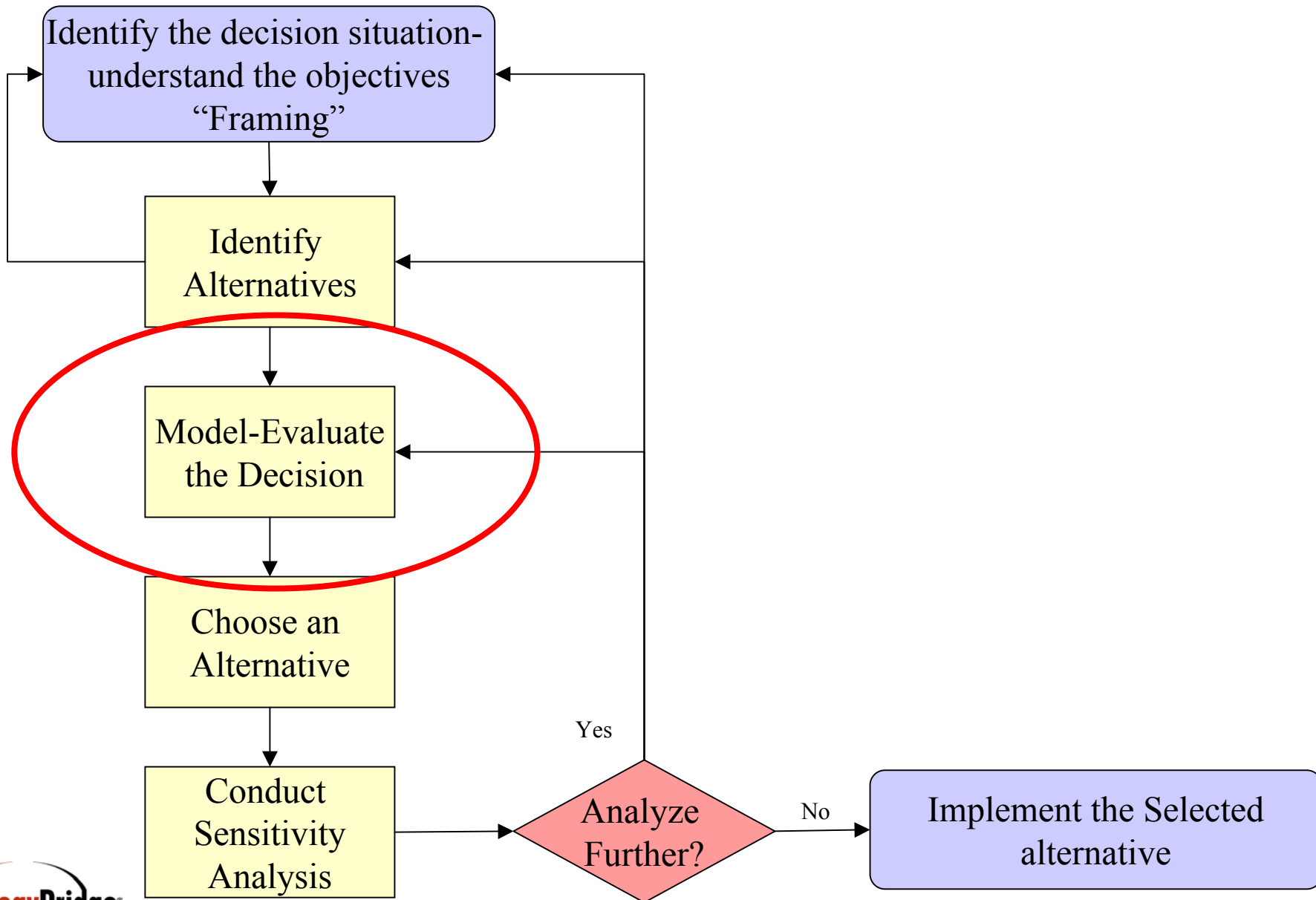
**After the problem has been framed, ask:**

**“How can we obtain the desired outcome?”**

- Challenge constraints - look at the problem from new angles
- Be creative, let process diverge
- Gather information, if necessary
- Withhold judgment until the evaluation phase

**How do you ensure that you are not considering the same old alternatives while falling into a “status quo” trap?**

# Trade Study Flow Chart



# Most Decision Problems are Multicriteria

- Satisfy science requirements
- Maximize design life
- Minimize lifecycle cost
- Maximize reliability
- Minimize costs of production
- Satisfy political stakeholders

## *Decision Criteria:*

The means by which a decision-maker measures the attributes of alternatives in order to identify and assess discriminators

# How do you compare objective and subjective measures?

How do you compare things with intangible properties?

***Can you compare apples to oranges?***

- Taste
- Aroma
- Acidity
- Price
- ?

**Question:**

Do political considerations ever factor in your trade studies?

# AHP Methodology in Trade Studies

**Prioritizes multiple tangible and intangible criteria:**

◆ **In most decisions, intangibles such as**

- political factors and
- social factors

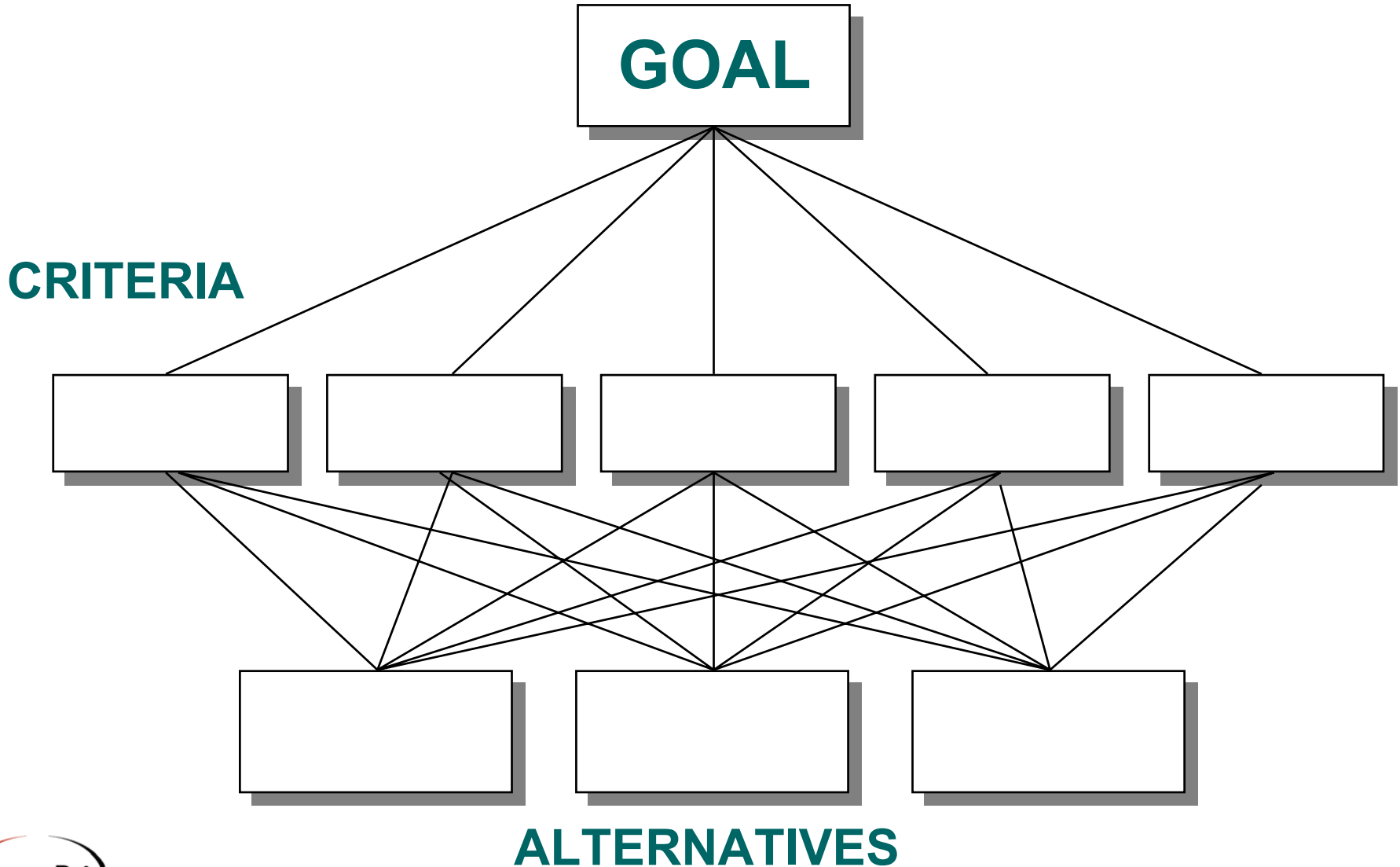
**take precedence over tangibles such as**

- economic factors and
- technical factors

- ◆ It is not the precision of measurement on a particular factor that determines the validity of a decision, but the importance we attach to the factors involved
- ◆ AHP assigns importance to all the factors and synthesizes this diverse information to make the best decision

***Example: the decision to use aluminum instead of a titanium alloy for the Boeing 777 wings was not the technically preferred alternative.***

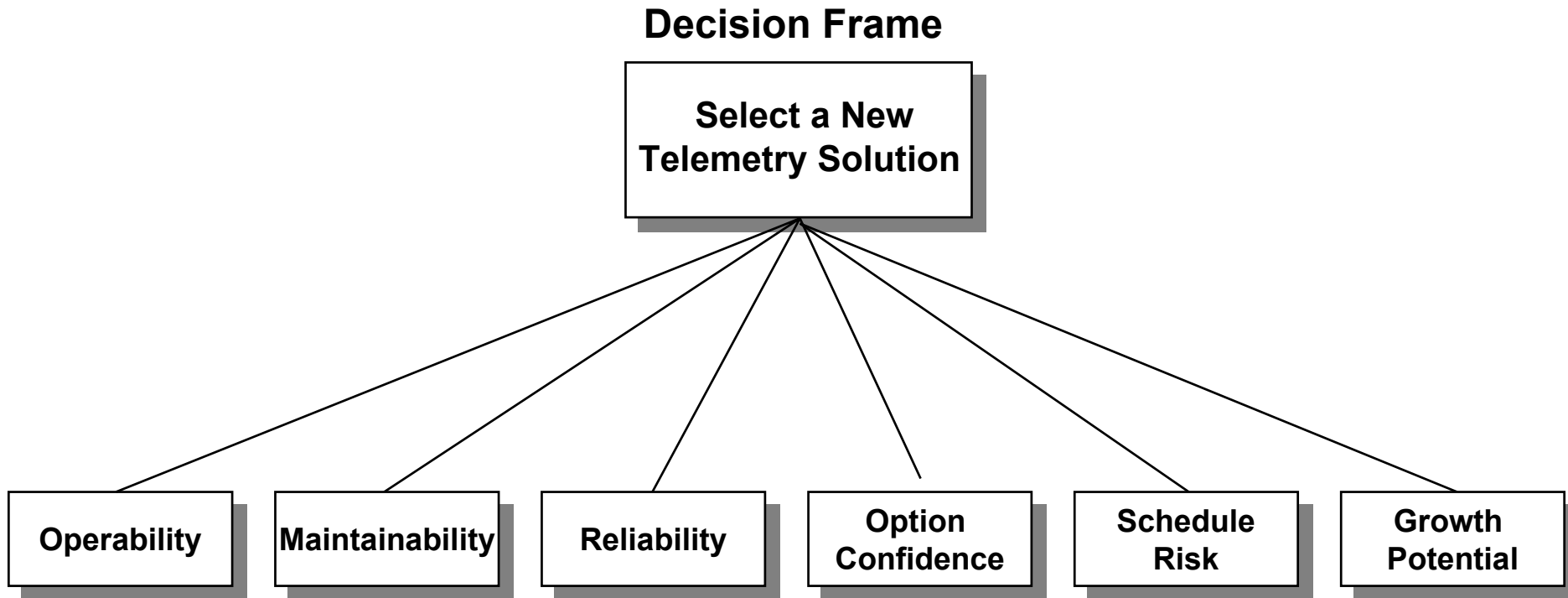
# The Analytic Hierarchy Process (Saaty- 1971)



# AHP Approach

- How does AHP capture human judgments?
  - AHP does not require you to make an absolute judgment or assessment.
  - Process uses relative assessment between two items at a time.
- In relative measurement a preference, judgment is expressed on each pair of elements with respect to the common "parent" element.

# Establish a Fundamental Objectives Hierarchy



# Choose a New Telemetry Solution for our satellite constellation

- **Operability**
  - measure of the ease with which an operator can comprehend the operating concept and operate the equipment
- **Maintainability**
  - Mean Time to Repair (MTTR)
- **Reliability**
  - Mean Time Between Failures (MTBF)
- **Option Confidence (i.e., will work as advertised)**
  - degree to which equipment will operate properly with spacecraft
  - product maturity
- **Schedule Risk**
  - risk that option can be delivered in time to meet next launch requirement
- **Growth Potential**
  - to be able to have a device which is modular and readily expandable and upgrade-able
  - capability of the design to readily accommodate technology insertion

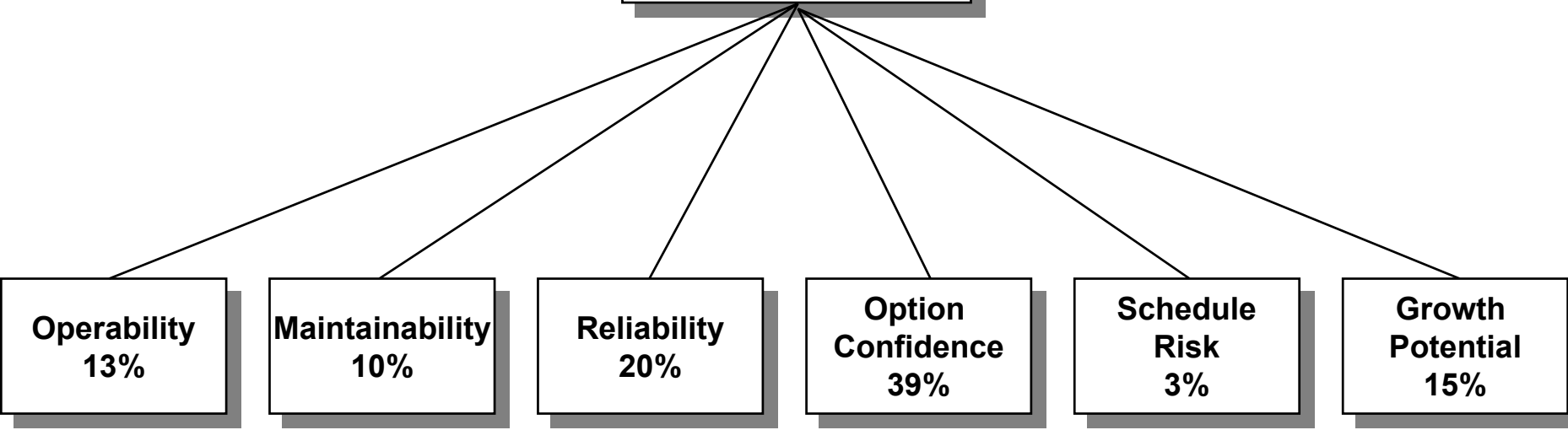
# Example Top Level Criteria Weights

							Row Total	Weight
	Operability	Maintainability	Reliability	Option Confidence	Schedule Risk	Growth Potential		
Operability	1	3	3	0.2	2	0.33	9.53	13.2%
Maintainability	0.33	1	0.25	0.2	5	0.33	7.11	9.9%
Reliability	0.33	4	1	0.2	6	3	14.53	20.1%
Option Confidence	5	5	5	1	9	3	28	38.8%
Schedule Risk	0.5	0.2	0.167	0.11	1	0.33	2.307	3.2%
Growth Potential	3	3	0.33	0.33	3	1	10.66	14.8%
							72.137	
							<b>Grand Total</b>	

- 1** Equal importance
- 3** Moderate importance of one over another
- 5** Strong or essential importance
- 7** Very strong or demonstrated importance
- 9** Extreme importance
- 2,4,6,8** Intermediate values

**GOAL**

**Select Telemetry Solution**



**Supplier A**

**GFE Option**

**Supplier B**

# Build Rating Scales

- Choose ratings scales that make sense
- Avoid constructed scales that are vulnerable to individual interpretation
  - For example, *Good-Better-Best*, *A-B-C*, etc.
- Tailored ratings scales for each criterion
  - Use objective measures, if possible

# Rating Alternatives

Sample Ratings Model

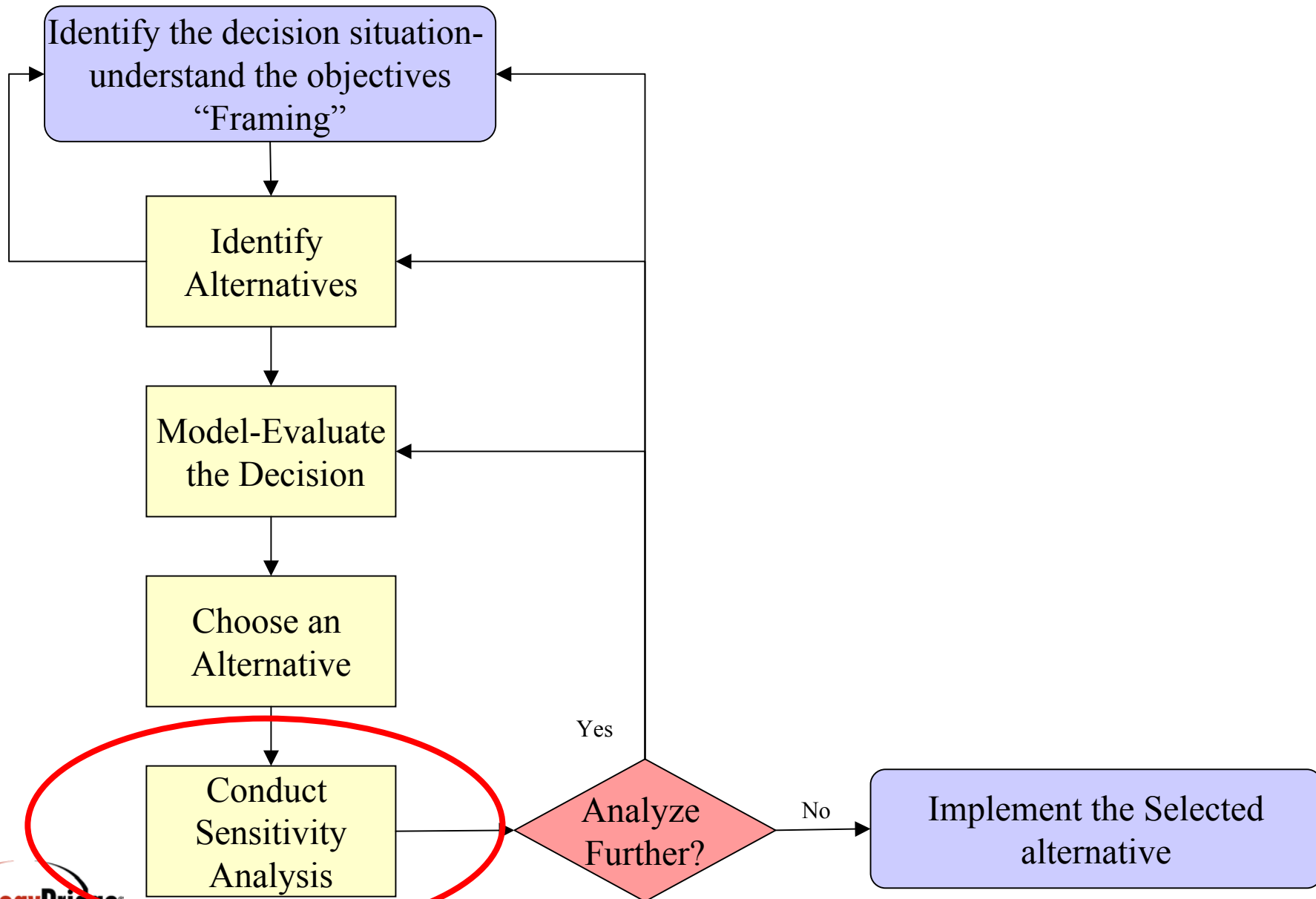
		<b>Operability</b>	<b>Maintainability</b>	<b>Reliability</b>	<b>Option Confidence</b>	<b>Schedule Risk</b>	<b>Growth Potential</b>	<b>Totals</b>
	weight	13%	10%	20%	39%	3%	15%	
<b>Supplier A</b>		100	60	60	60	30	100	70.3
<b>GFE Option</b>		100	60	100	100	60	30	84.3
<b>Supplier B</b>		30	100	100	30	100	60	57.6

100	< 40 hrs Training	MTTR < 8 p-hrs	MTBF >10K hrs	Very High	Low	Modular Design
60	40-80 hrs Training	MTTR 8 - 24 p-hrs	MTBF 5K - 10K hrs	High	Moderate	Upgradeable
30	80-100 hrs Training	MTTR 24 - 40 p-hrs	MTBF 1K - 5K hrs	Moderate	High	Poor Growth Potential
0	>100 hrs Training	MTTR > 40 p-hrs	MTBF < 1K hrs	Low	Very High	Closed Architecture

# Summary of AHP Advantages

- Easy to use in trade studies
- Organizes, prioritizes and synthesizes complexity within a rational framework
- Breaks down tangible and intangible criteria into manageable components
- Fosters critical discussion and examination of implicit assumptions when used with diverse groups
  - Makes it possible to deal with conflicts in perception and in judgment

# Trade Study Flow Chart

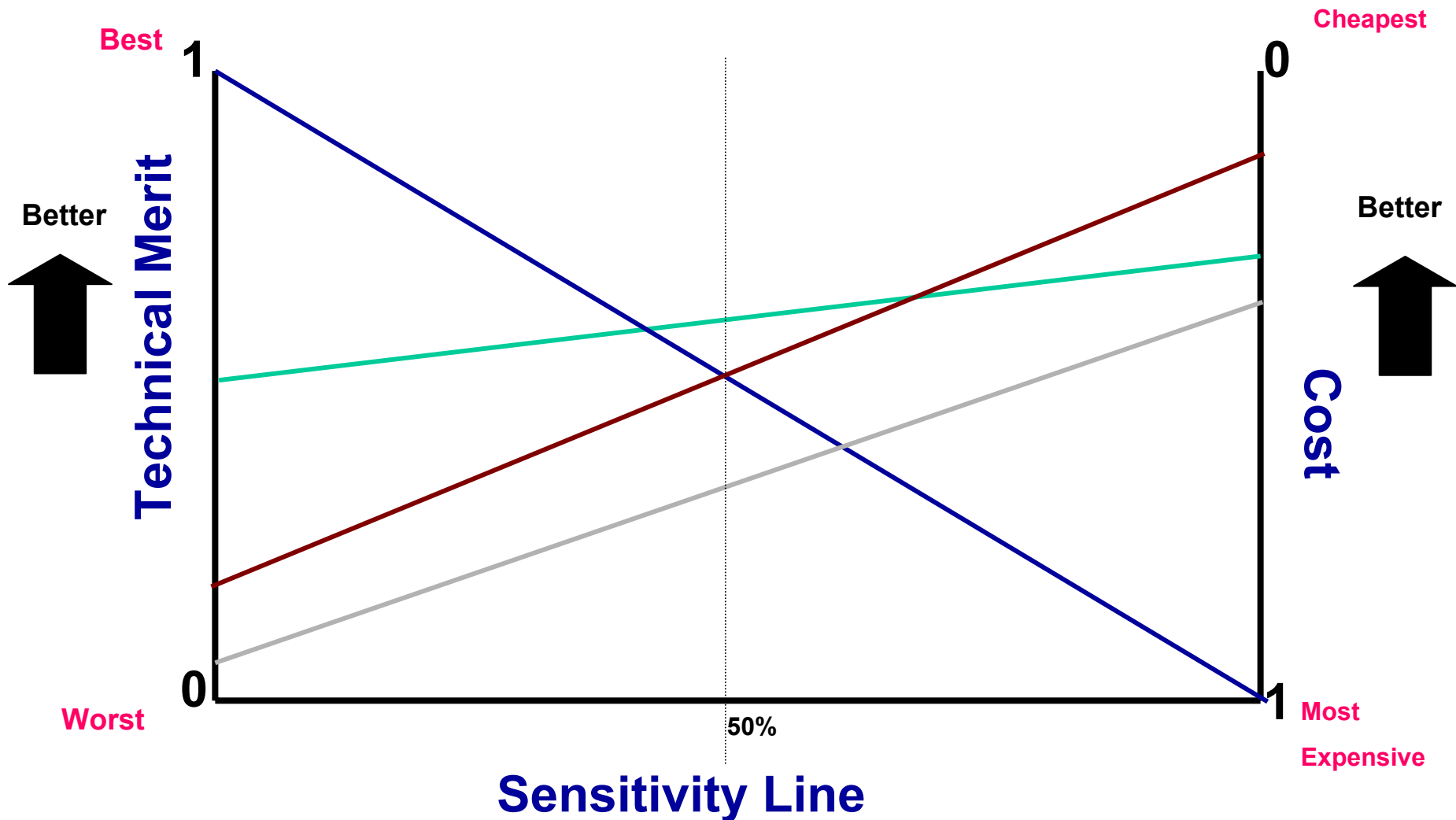


# Sensitivity Analysis

- Sensitivity analysis answers the question: "What makes a difference in this decision?"
- Sensitivity analysis determines whether small changes in judgments affects the final weights and rankings of the alternatives.
  - May lead the decision-maker to reconsider the decision frame or the sufficiency of alternatives
- If so, the decision-maker may want to review the sensitive judgments.

# Technique: Two-Way Sensitivity Graph

(Comparison of One Factor to Another)



# Questions?

