A Decision Analysis Framework for Risk Management of Near Earth Objects

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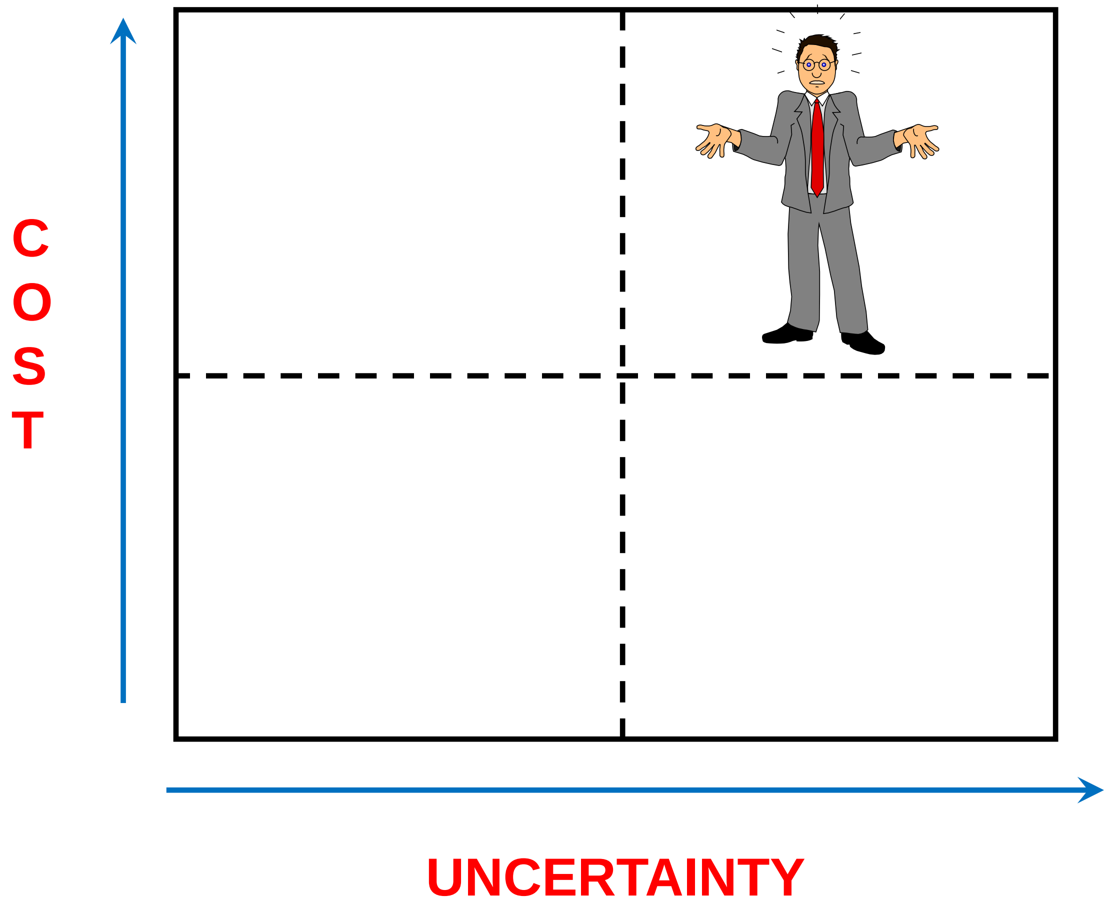
Risk, Risk Assessment, and Risk Management

- Risk = quantitative function of vulnerability, probability, and consequences.
- Risk analysis = quantitative evaluation of risk, including analysis of uncertainties (i.e., probabilistic risk analysis or PRA). Risk analysis of rare, catastrophic events requires specialized approaches (e.g., analysis of upper tail of distribution)
- Risk management = reduction of any or all of the factors contributing to risk
- Risk management analysis (i.e., decision analysis) = risk analysis plus quantitative analysis of the risks, benefits, and costs of different risk management alternatives; considering tradeoffs, multiple stakeholder preferences, risk aversion, etc. Results in a ranking of alternative strategies for risk management
- Value of information analysis = method to determine the value of uncertainty reduction via data collection, research, etc. in terms of influence on choice of alternatives

Difficult Decisions



Typical ‘Alternative Focused’ Decision Process

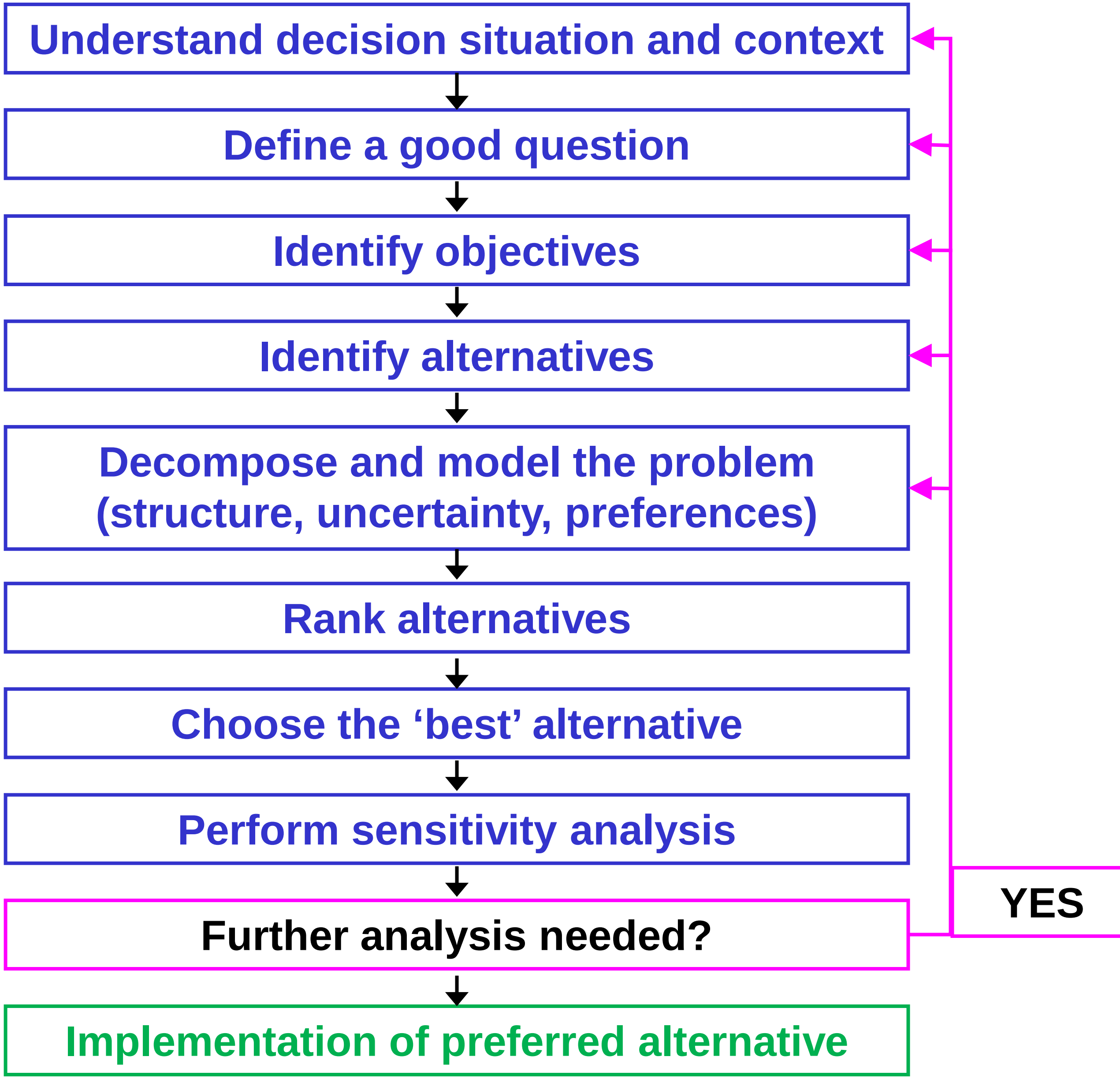
- Decision problem is identified-- usually because of ‘dissatisfaction’ with the present state of affairs
- Decision-maker (or group) thinks about it, generates some alternatives or comparisons
- Decision-maker selects some criteria that reflect consequences of choosing alternatives (often focused on those which have ‘hard’ data, rather than focusing on values and objectives). Uncertainty is often ignored
- Decision-maker *might* consult others
- Decision is made
- Some sort of optimization process may follow

Problems

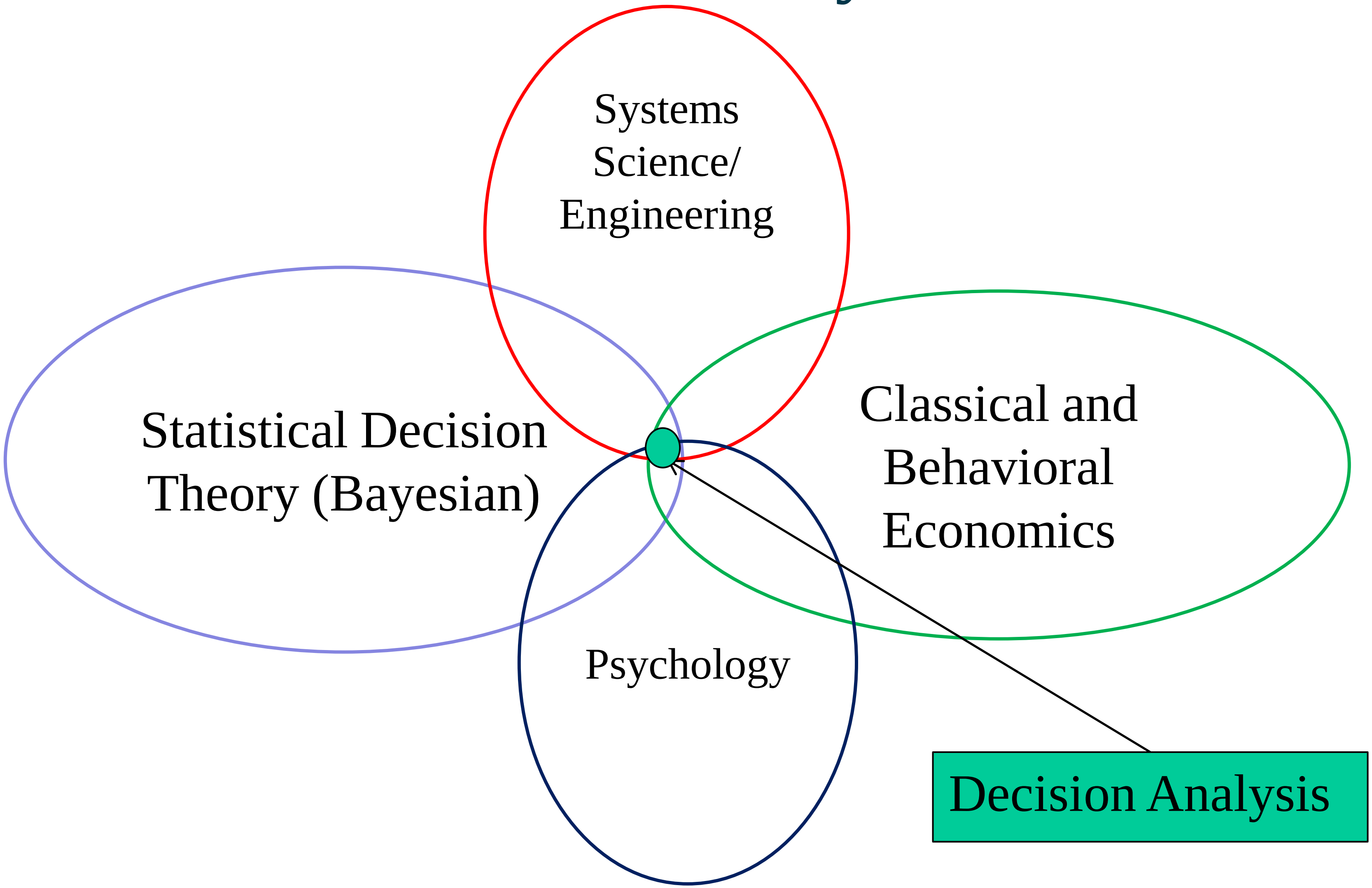
- Ø A wealth of literature and case studies indicate that this process results in suboptimal (less effective, more costly, etc.) decisions in cases where the decision is complex and subject to great uncertainty (i.e., difficult or “wicked” decisions)
- Ø Usually does not involve multiple stakeholders
- Ø Focuses on optimizing within constraints, rather than focusing on what the involved parties really want to achieve
- Ø Often ignores uncertainty and risk aversion
- Ø Often the decision criteria are unclear, so if challenged the decision-maker is unable to offer a transparent, defensible process
- Ø Proper risk and decision analysis can help design better (i.e., more effective, less costly, etc.) strategies : e.g., what *should* be done vs. what *can* be done

An Alternative to Alternative Focused Thinking:

Objective Focused Decision Analytic Process



Decision Analysis



Let's Buy a Car!

Decision Context

- Ø Need vs. want
- Ø Multiple stakeholders: wife, husband, kids, dogs
- Ø Timing: now vs. waiting
- Ø Resource issues: saving up, trading in, financing, leasing
- Ø Risk aversion

Possible Objectives (What Do We Want?) / Attributes (How Do We Measure?)

Possible Objectives (What Do We Want?)	Attributes (How Do We Measure?)
Ø Color →	White to red
Ø Appearance →	Mundane to sexy
Ø Performance →	Slow to fast
Ø Safety →	Low to high
Ø Fuel economy →	Low to high
Ø Exterior/interior size →	Small to large
Ø Reliability →	Low to high
Ø Longevity →	Short to long
Ø Capital cost →	Low to high
Ø Maintenance cost →	Low to high
Ø Accessories →	Few to many
Ø Cup holders (!) →	Few to many

Simple Decision Matrix

	Sportscar	Minivan	Sedan	Truck
Appearance	✓✓✓	✓	✓✓	✓
Performance	✓✓✓	✓	✓✓	✓
Safety	✓	✓✓✓	✓✓✓	✓✓
Fuel Economy	✓	✓✓	✓✓✓	✓
Size	✓	✓✓✓	✓✓	✓✓✓
Reliability	✓	✓✓✓	✓✓✓	✓✓✓
Longevity	✓	✓✓	✓✓✓	✓✓
Low cost	✓	✓✓	✓✓✓	✓✓
Accessories	✓	✓✓✓	✓✓	✓✓

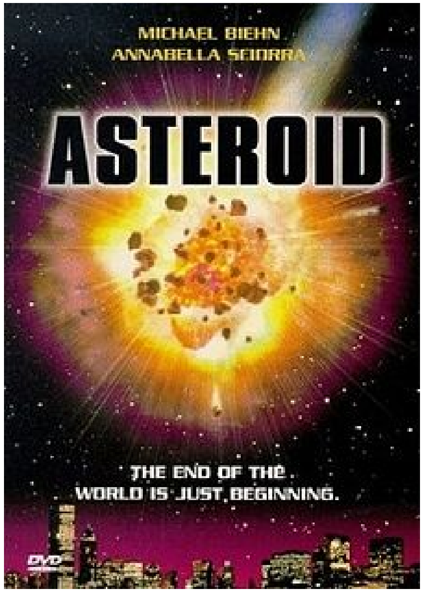
Considerations Not Addressed by Matrix

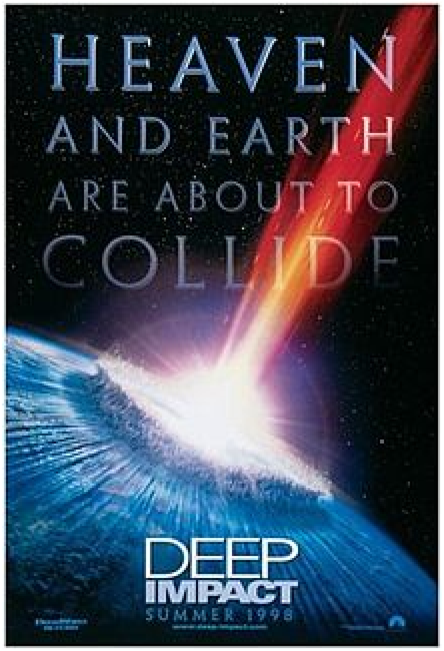
- Ø Simple, but perhaps too simple
- Ø Differential weighting of objectives
- Ø Utility function: how all this is crunched together
- Ø Uncertainties (e.g., reliability)
- Ø New vs. used vs. lease
- Ø Negotiation (i.e., resulting in less cost, greater trade-in value, etc.)
- Ø Multiple choices within categories

Sidebar: Insurance

- Ø Insurance may have a role in risk management, but insurance is simply a means to *transfer* risk from affected parties to the insurer
- Ø The insurer charges $$ to accept risk (directly for private, via taxes for public)
- Ø There may be no particular incentive to *reduce* risk in the case of private insurance, as the insurer makes $$ from a risky situation (as long as they charge enough!). As public insurance is funded by public $$, there may be more incentive
- Ø Insurance is not really risk management *per se*; as it only typically addresses the consequences of a risky scenario (i.e., losses)
- Ø Insurers often rely heavily upon actuarial statistics, which have limited predictive ability for rare, catastrophic events
- Ø Insurers may encourage risk reduction as good business practice or government policy

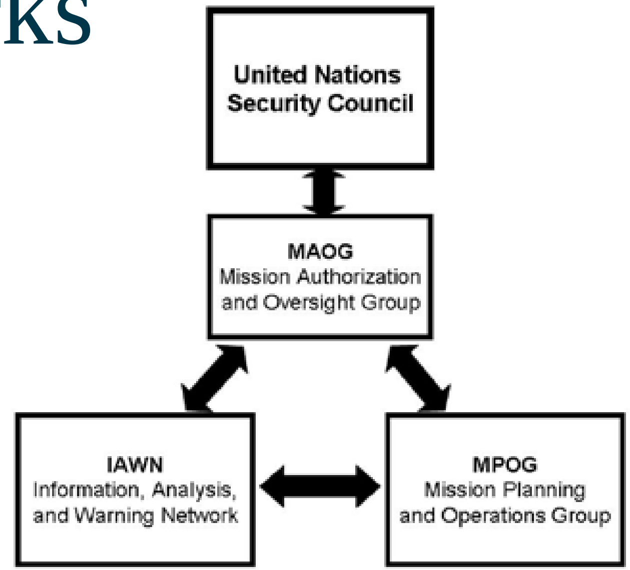
The Sky is Falling!



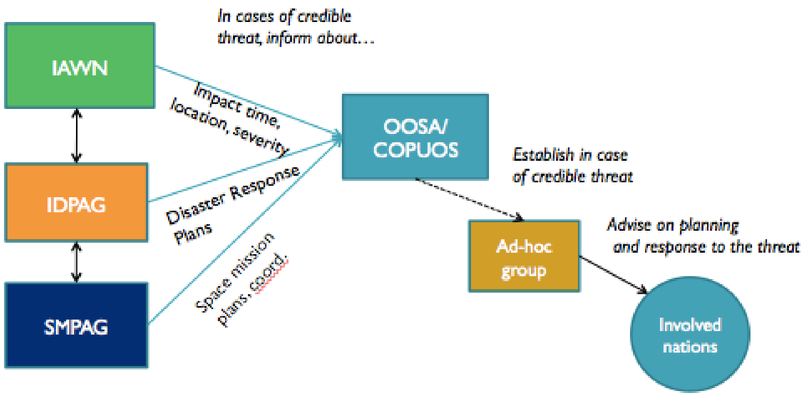


Decision Frameworks

- “Failing to provide a decision-making framework before a threatening NEO is discovered will result in lengthy argument, protracted delays, and collective paralysis. Such delays will preclude a deflection and force the world to absorb a damaging – albeit preventable – impact. With the lead time for a decision typically needed at least 10-15 years ahead of a potential impact, we should now begin to forge that vital decision-making capacity.” (ASE 2008)



From ASE 2008, Asteroid Threats: A Call for Global Response



From the Scientific and Technical subcommittee of the UN’s Committee on the Peaceful Uses of Outer Space (COPUOS)

Uncertainties

- Number of NEOs
- Orbital and physical characteristics (size, mass, etc.)
- Intervention effectiveness, timing
- “Keyholes” of potential NEO return
- Warning time
- Risk corridors
- Cascading events
- Type and scale of post-impact and spin-off events

Figure 7. Risk Corridor visualization for a particular NEO

Figure 8. Risk Corridor visualization for multiple threatening NEOs

From ASE 2008, Asteroid Threats: A Call for Global Response

Decisions

- Ø How/when to gather more information
- Ø Whether, when, and how to deflect
- Ø How/when to manage public perception
- Ø How/when to manage impact if deflection is not effective (i.e., disaster management)

Influences

- Ø NEO characteristics (location, orbital characteristics, size, mass, composition)
- Ø Impact probability and location
- Ø Time duration from: discovery of the impact possibility to the date of impact, discovery to deflection decision made, discovery to the date when the intervention must be accomplished, mission decision to launch of spacecraft, launch until arrival, etc.
- Ø Costs of information collection
- Ø Costs and technological feasibility of alternatives
- Ø Risks of interventions
- Ø Requirements for inter-agency and international cooperation
- Ø Need to inform the public

Possible Objectives

- Minimize mortality/injury
- Minimize critical infrastructure damage (e.g., power, transportation, communications, food production, etc.)
- Minimize ecological damage
- Minimize property damage
- Minimize ungrounded speculation, fear, panic, etc.
- Minimize resource utilization
- Minimize cost (or stay within a budget)
- Minimize legal/regulatory issues (e.g., nuclear explosives in space)
- Maximize inter-agency/government coordination

- *Many of these have 'natural' measures for attributes, some would need to be scaled*
- *All attributes can be converted to $$s (e.g., to estimate net benefit) but this is not necessary*

Utility Functions

- Serve to integrate multiple attributes
- Example:

$$U(x_1, x_2) = w_1 u_1(x_1) + w_2 u_2(x_2) + w_3 u_1(x_1) u_2(x_2)$$

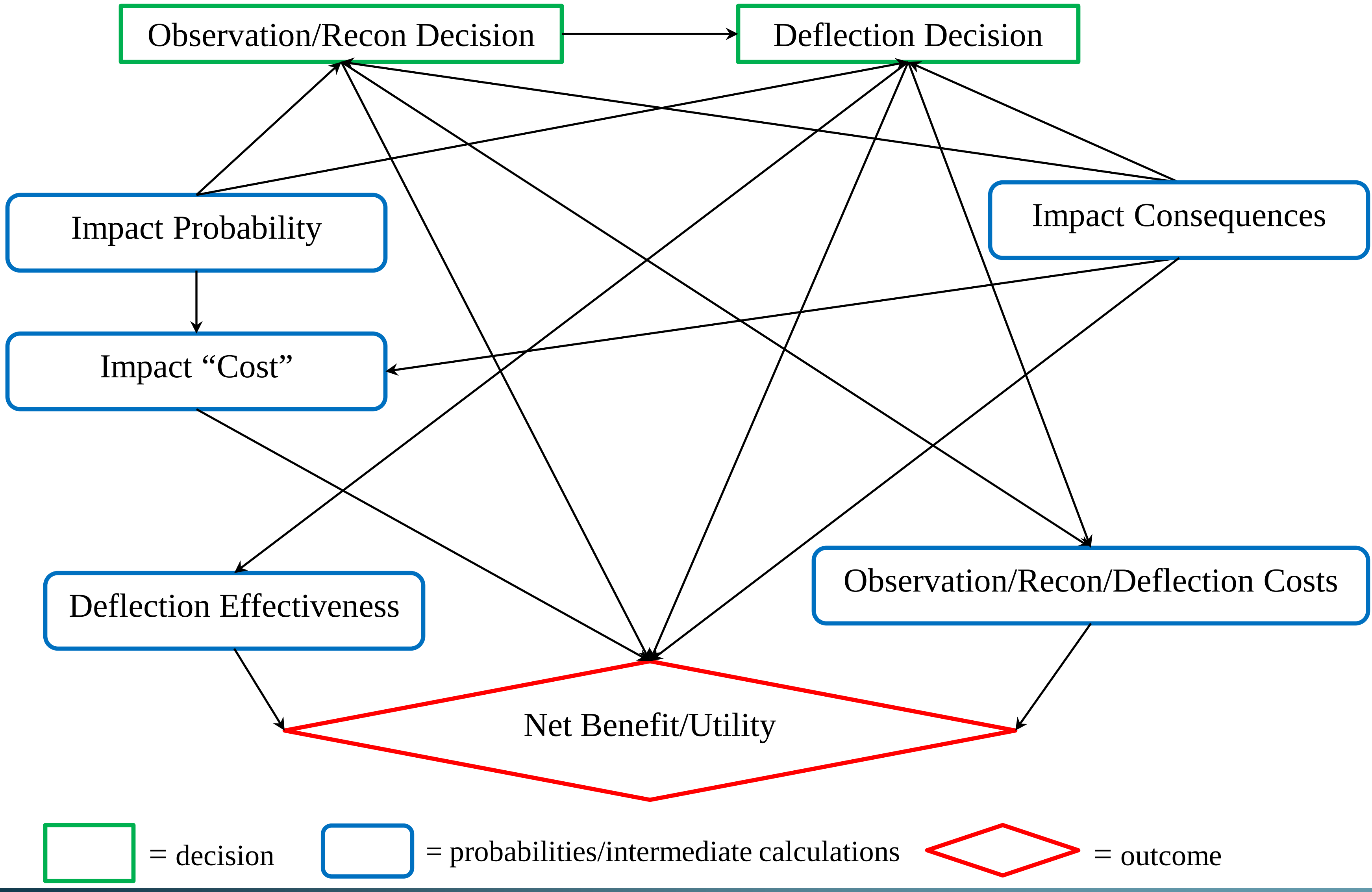
Where:

U= utility of a set of attributes

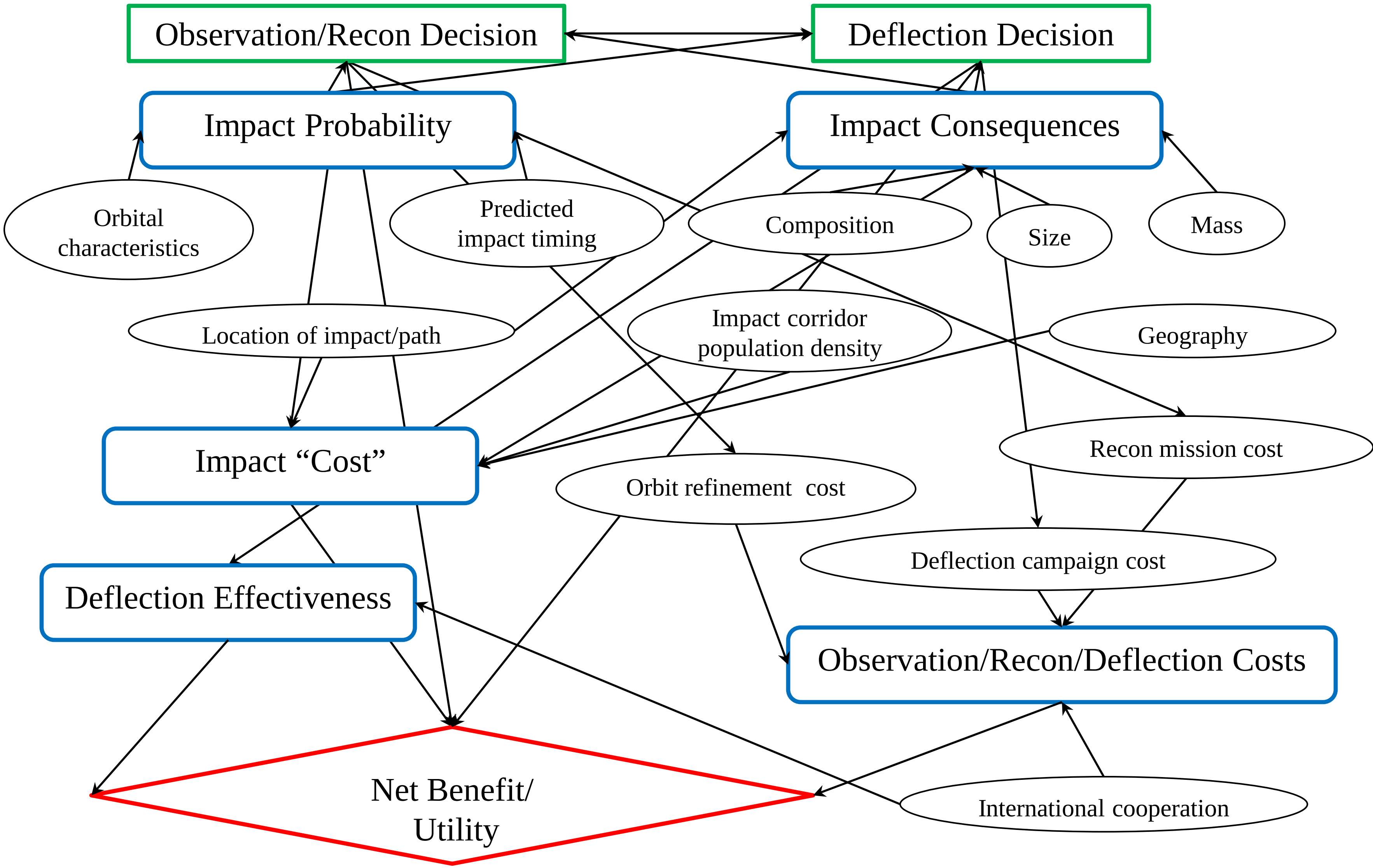
u= utility associated with a particular attribute *x*

w= scaling weights assigned to address tradeoffs

Highly Simplified Influence Diagram for Intervention



Somewhat Less Simple Influence Diagram



Alternatives (at this point)

Uncertainty Reduction

- Increased or different Earth-based observation (optical, radar)
- Increased or different space-based observation
- Reconnaissance mission
- Transponder on surface
- Combinations of above

Deflection

- Do nothing and hope for the best
- Kinetic impact
- Nuclear blast
- Gravity tractor
- Combinations of above, or redundancy

Non-deflection risk management

- Evacuation, planning
- Disaster management
- Insurance
- Combinations of above

Structure

- Complex sequential decisions with multiple stakeholders and attributes
- Dynamic decision structure desirable (or at least a static structure, implemented iteratively)
- Weighting of attributes and utility function would need to be elicited
- Risk aversion will likely change over time (i.e., more aversion closer to event)

Other Considerations

- Nature of observation, space travel, etc. is changing
- Resource considerations are crucial (i.e., interventions will not be cheap!), but efficiencies may exist (e.g., NEO capture, mining)
- The risks/costs associated with less-than careful consideration of the decisions may be substantial
- The risks/costs of waiting too long may be very substantial

Practical Considerations

- Ideally a dynamic, systems-level model would be combined with probabilistic risk and decision analysis calculations
- Integration with with GIS would allow determination of differential risks and consequences over a spatial area
- Many of the ‘input’ variables and probabilities in the model may be determined via formal expert and stakeholder elicitation in cases where good data do not exist
- A Web-based, open-source platform and decision-support tool may facilitate multi-stakeholder, -agency, and -nation communication and decision-making
- A sustainable decision-making structure that employs analysis should be crafted so that it is resilient to organizational/political changes
- *This process could also apply to other NEO characterization/mitigation or space travel decisions (e.g., mission planning)*

Final Thoughts

- There's no 'right' or 'wrong' way to make a decision (*people make decisions- models don't make decisions!*), but decision analysis helps people make more informed, transparent, and defensible decisions
- The more complex and uncertain the decision, and the larger the consequences of making a wrong decision, the more these methods can help.
- Recent examples of resource allocation to manage rare events: Katrina, Indonesian tsunami, World Trade Center, etc.
- NEO risk not a simple problem, so a simple model will probably not be the most informative (but can be done in a staged fashion)

Thank You!