Systems Engineering Tradeoff Study Process Framework

Matthew V. Cilli
Systems Engineering PhD Candidate
Stevens Institute of Technology, Hoboken, NJ
mcilli@stevens.edu

Gregory S. Parnell
Visiting Professor of Industrial Engineering
4207 Bell Engineering Center,
Department of Industrial Engineering, University of Arkansas
gparnell@uark.edu

How We (The Decision Analysis WG) Got Started

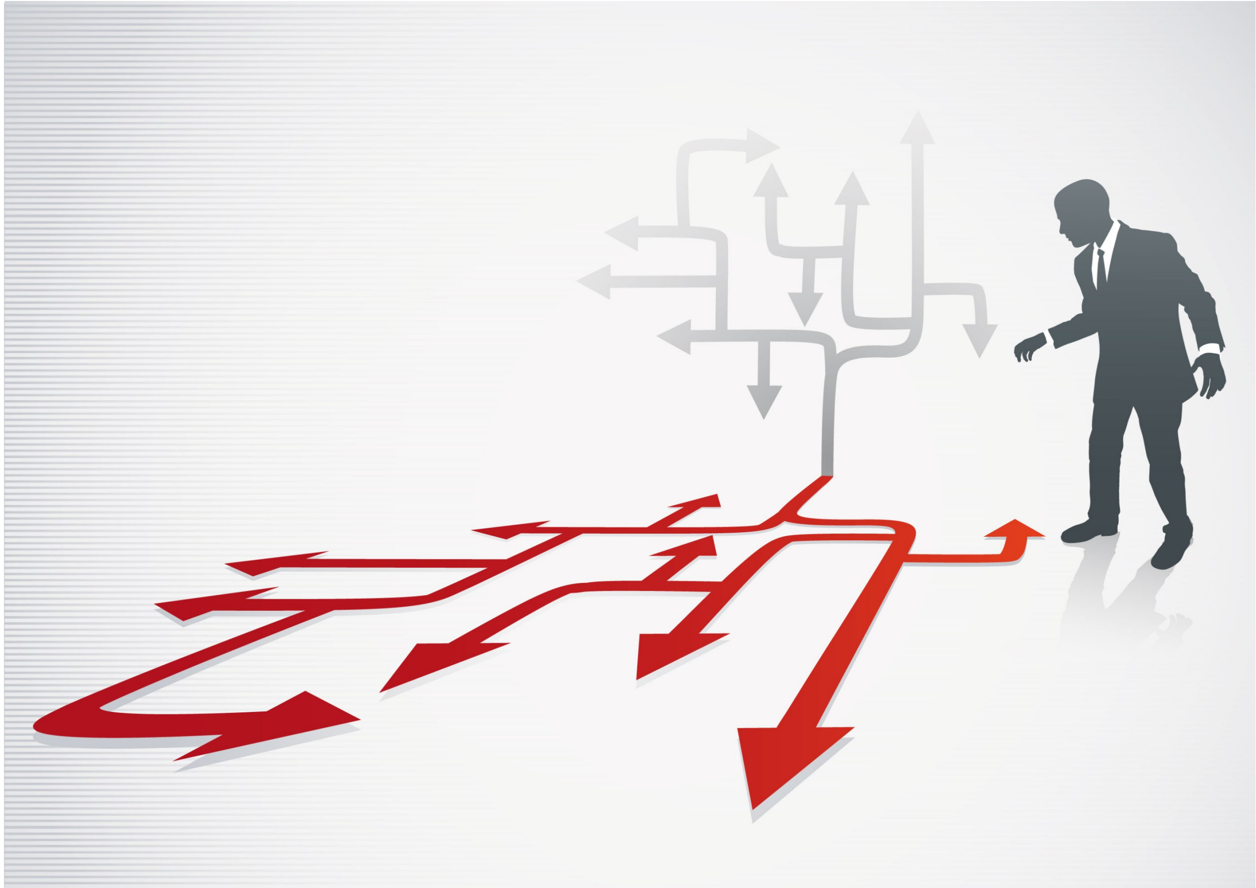
The Decision Analysis Working Group Emerged from INCOSE Corporate Advisory Board's desire for a Tradeoff Study Guidebook

- Demand for a guidebook on tradeoff studies from the INCOSE Corporate Advisory Board.
- Not aware of good industry information that crosses the life cycle and aligns with INCOSE process guidance (Handbook, SEBok, ISO/IEC 15288, DAG,CMMI).
- Referred to the Decision Analysis WG as an initial product within their charter.
  - Frank Salvatore, Decision Analysis Working Group Chair
  - Dr. Dennis Buede, INCOSE Fellow
  - Mr. Matt Cilli
  - Dr. Greg Parnell, INCOSE Fellow
  - Mr. Rich Swanson
- Decision Analysis Working Group Plan
  - Revise Decision Management section of INCOSE Handbook ✓
  - Revise Decision Management section of SEBoK ✓
  - Present at INCOSE 2014 ✓
  - Write Guidebook

Successful Systems Engineering Requires Good Decision Making

Many systems engineering decisions are difficult decisions in that they include

- Numerous stakeholders
- Multiple competing objectives
- Substantial uncertainty
- Significant consequences
- High accountability



New Product Developments Entail an Array of Interrelated Decisions

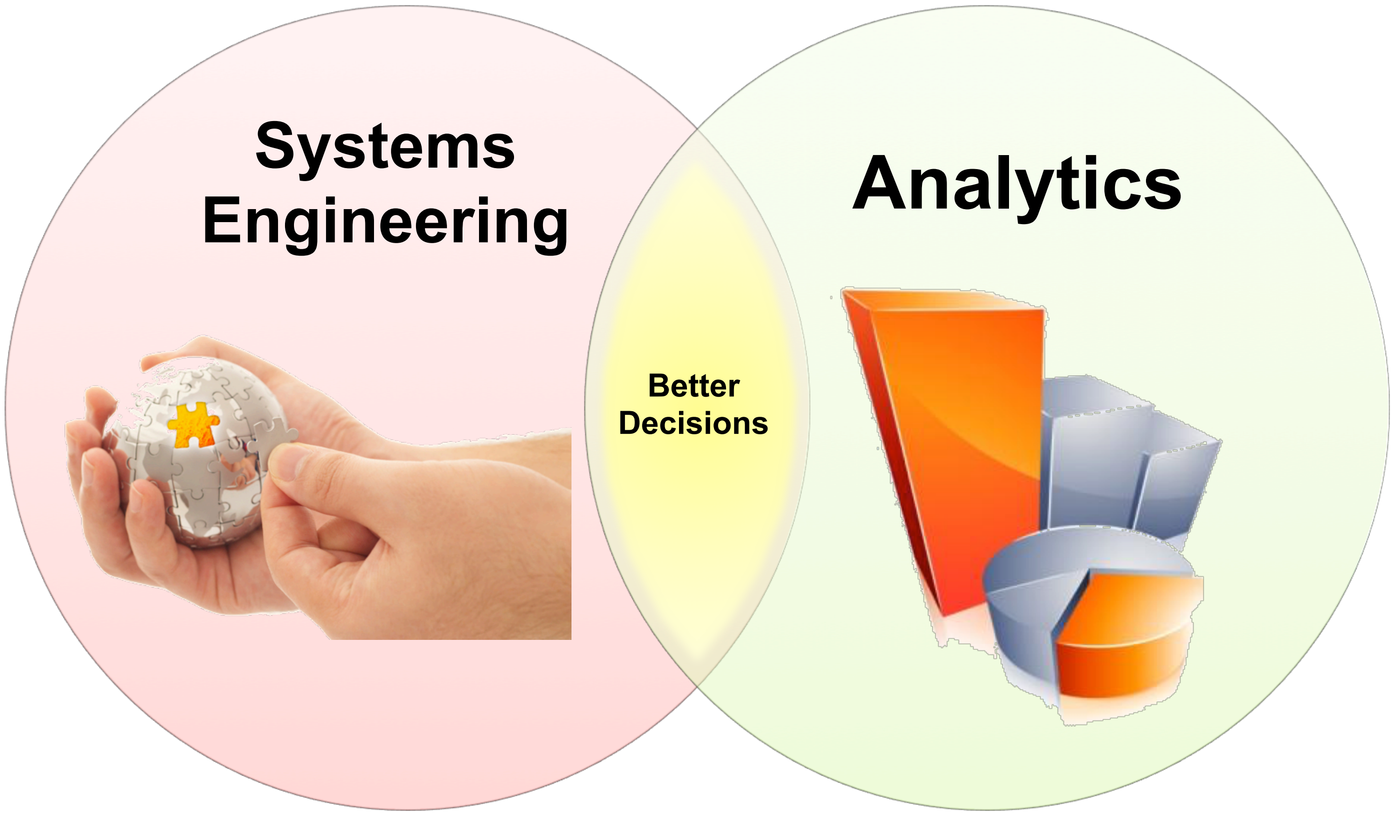
The table to the right provides a partial list of decision opportunities that are commonly encountered throughout a system's lifecycle. Decisions that underpin

- Initial business case development,
- Requirements writing,
- System architecture design,
- Conceptual design, Detailed design,
- Production strategies,
- Maintenance plans.

Research	**Assess Technology Opportunity / Initial Business Case** Of all the potential system concepts that could incorporate the emerging technology of interest, do any offer a potentially compelling and achievable market opportunity? Which should be pursued, when, & in what order?
Concept	**Inform, Generate, and Refine a Capability Development Document** What requirements should be included? What needs to be accomplished and what can be traded away to achieve it within anticipated cost & schedule constraints? How should requirements be expressed such that they are focused yet flexible? How can the set of requirements be demonstrated to be sufficiently compelling while achievable within anticipated cost & schedule constraints? **Create System Architecture Alternatives and Select Best** After considering the system level consequences of the sum of architecture design choices across the full set of stakeholder value (to include cost and schedule), which architecture alternative should be pursued?
Development	**Select / Design Subsystems** After considering the system level consequences of the sum of subsystem design choices across the full set of stakeholder value (to include cost and schedule), which subsystem alternatives should be pursued? **Select / Design Components / Parts** After considering the system level consequences of the sum of component design choices across the full set of stakeholder value (to include cost and schedule), which component alternatives should be pursued? **Select / Design Test and Evaluation Methods** What is the prototyping plan? What tests and evaluation should be performed? What is the verification plan?
Prod.	**Craft Production Plans** What is the target production rate? To what extent will low rate initial production be utilized? What is the ramp up plan? What production process will be used? Who will produce the system? Where will the system be produced?
O&S	**Generate Logistics Approach** What is the logistics concept? What is the preventive maintenance , corrective maintenance, & spare parts plan?

High Quality Decisions Emerge From The Intersection of SE & Operations Research.

Many of these decisions may benefit from the holistic perspective of the systems engineering discipline coupled with the reasoning tools emerging from the operations research community.



Keyword Cloud for Systems Engineering Journal 2009-2013

Decision making is a frequently recurring topic in SE Journal

Notes:

- "Systems Engineering" excluded (dominated keyword cloud and added no new information)
- Plurals merged with singular to most frequent form
- Variations of "Systems of Systems" consolidated.
- Variations of DODAF consolidated
- Architectural framework, architecture framework, architectural pattern consolidated into "Architecture"
- Risk analysis, risk assessment, risk management, risk modeling, risk perception, and risk-based consolidated into "Risk"
- Decision analysis, decision making process, decision support process, decision support systems, decision support tools, decision support, decision theory, decision trees consolidated into "Decision making"

The Role of a Composite Model (Decision Support Model)

A composite model integrates outputs of otherwise separate models into a holistic system view mapping critical design choices to consequences relevant to stakeholders. A decision support model helps decision maker (and those executing the systems engineering tradeoff analysis) overcome cognitive limits without oversimplifying the problem.

Without Decision Model

Aggregate
Force
Effectiveness

Entity
System Performance

Engineering
Physics of
components

Reference: Parnell, Gregory S., Driscoll, Patrick J., Henderson, Dale L., *Decision Making In Systems Engineering and Management, 2011, 2nd Edition*. John Wiley & Sons, Inc. Hoboken, NJ 2011.

With Decision Model

Aggregate
Force
Effectiveness

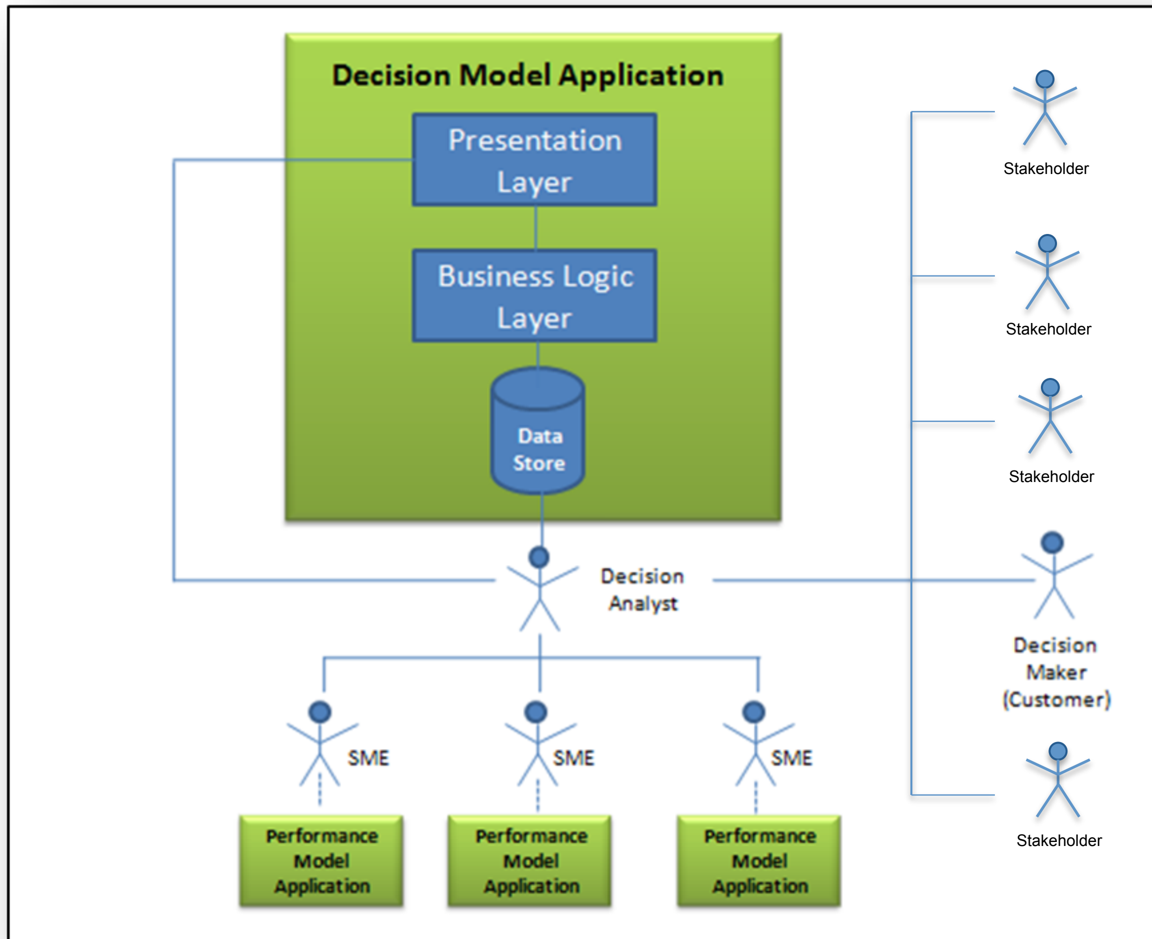
Composite
Model

Entity
System
Performance

Engineering
Physics
of components

Integration Pattern for Decision Support (Composite) Model

Note the process does not replace the engineering models, performance models, operational models, cost models, or expert opinion prevalent in many enterprises but rather complements such tools by synthesizing their outputs in a way that helps decision makers thoroughly compare relative merits of each alternative in the presence of competing objectives and uncertainty.



Decision Management Process

Decision management process transforms broad statements of a decision situation into a recommended course of action and associated implementation plan for system solutions that best balance competing objectives in the presence of uncertainty.

Decision Centric Systems Engineering Process

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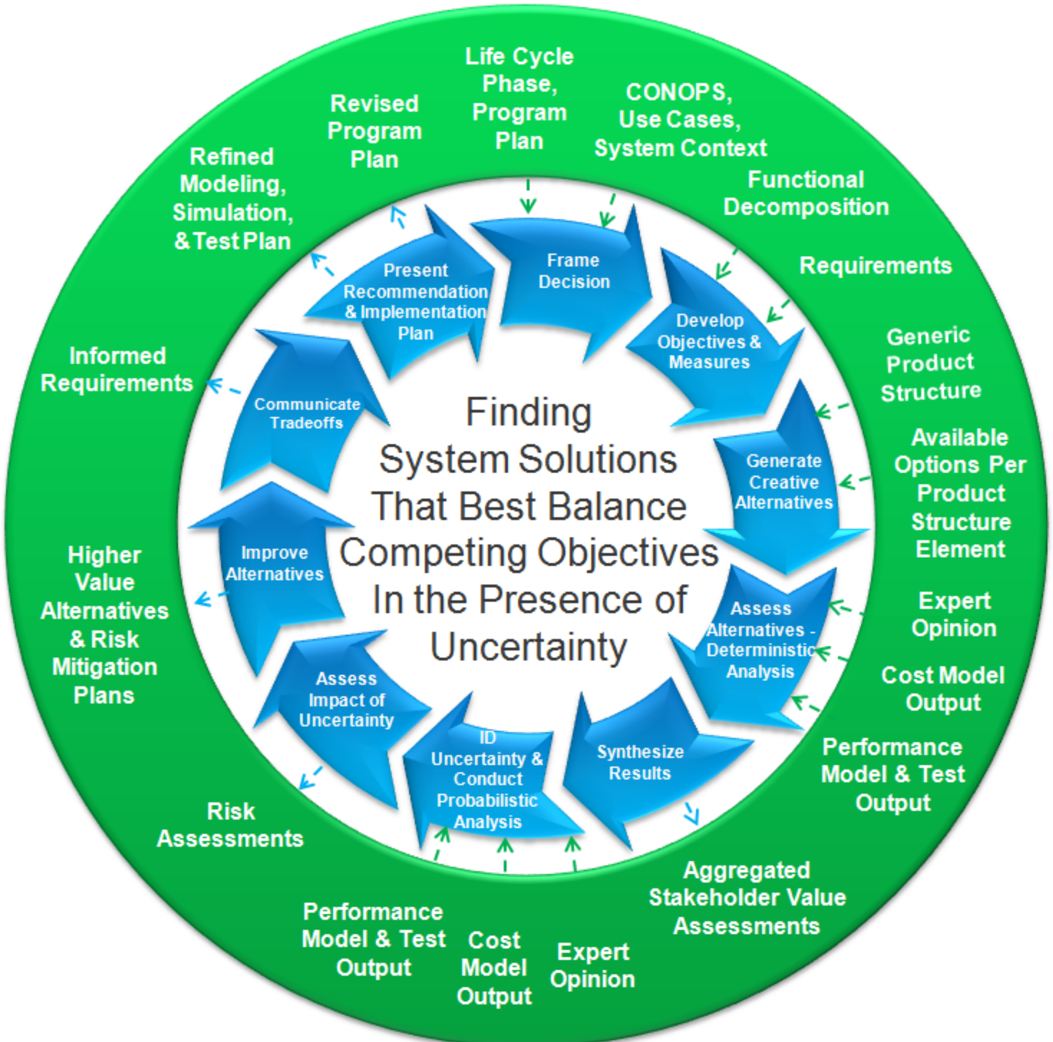
Positioning decision making as central to all systems engineering activity helps ensure that SE efforts are rightfully interpreted as relevant and meaningful and thus maximize the discipline's value proposition to new product developers and their leadership.

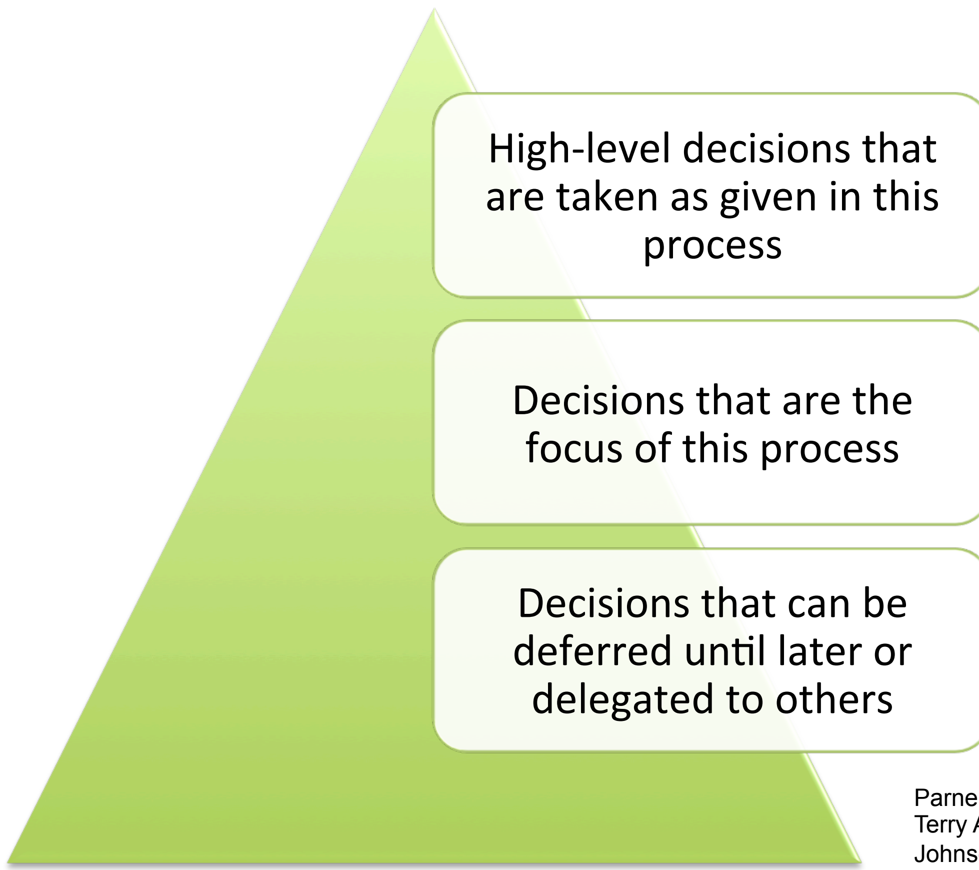


Decision Management Process Walk Through

The balance of this talk will unpack this 10 step decision management process, one step at a time.

Framing Decision

Framing often involves understanding expectations regarding the type of action to be taken as a result of the decision at hand as well as decisions anticipated in the future.



Parnell, Gregory S., Bresnick, Terry A., Tani, Steven N., Johnson, Eric R.; *Handbook of Decision Analysis;* John Wiley & Sons. 2013.

Developing Objectives – Discovering Potential Objectives

Capturing the voice of the stakeholders usually involves asking a whole bunch of questions.

- Generate a "wish list" that need not be structured at this point
- Conduct literature search
- Expand questions developed in decision process step w/ additional stakeholder interviews and focus groups
  - Stakeholder interviews
    - Typical questions (for performance related questions)
      - What is the envisioned capability?
      - How was it handled in the past?
      - Why isn't that good enough?
      - What would be the best possible outcome? Why?
      - What would be the worst possible outcome? Why?
      - What features would you like see on a new system? What would that feature do? Why is that important?
      - Are there any features you hope not to see on a new system? Why? Why do you care about this system?
    - For the defense system acquisition type decision tasks,
      - What is the envisioned system's role within a System of Systems?
      - With what other systems does the system of interest interact?
      - What would happen if the incumbent system of interest didn't exist? Why? How so? What do you mean?

Establish Fundamental Objectives

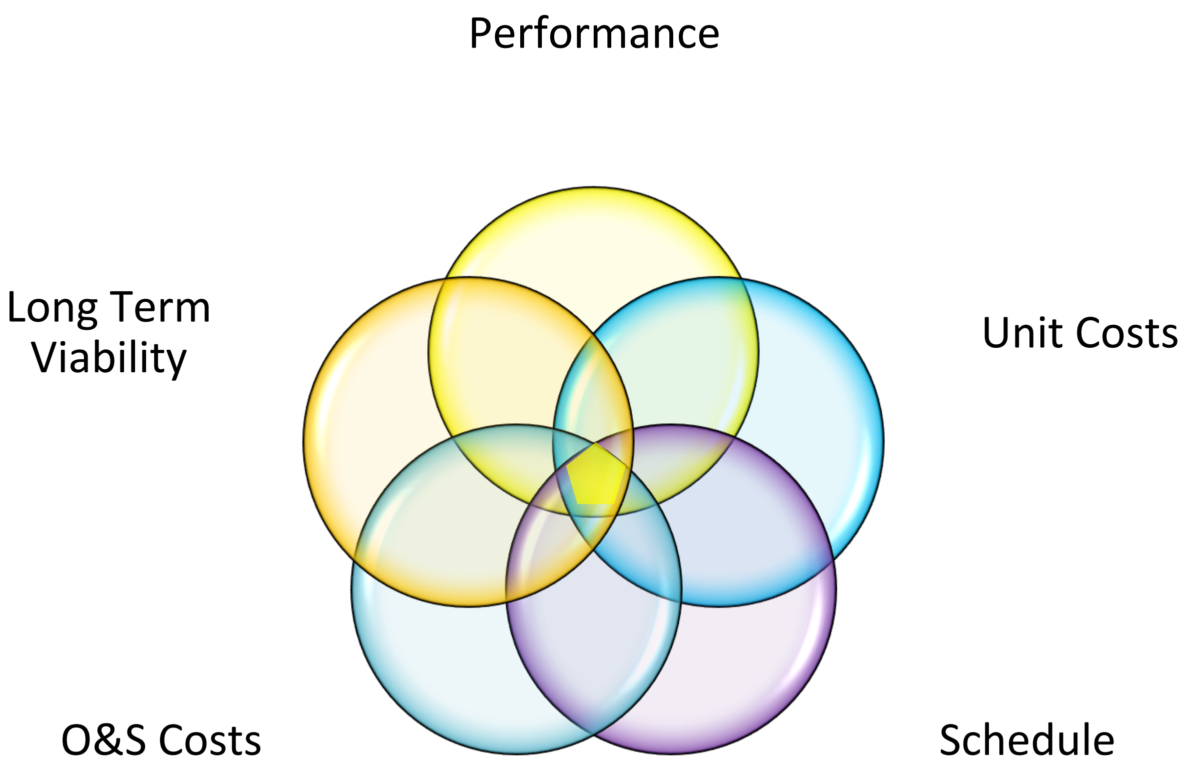
Categorizing each objective as fundamental, means-to-an-end, process, or strategic helps create focus.

Objective Category	Definition
Fundamental	The ends objectives used to describe the consequences that essentially define the basic reasons for being interested in the decision
Means	Objectives that are important only for their influence on achievement of the fundamental objectives.
Process	Objectives concerning how the decision is made rather than what decision is made.
Strategic	Objectives influenced by all of the decisions made over time by the organization or individual facing the decision at hand.

Reference: Edwards, W., Miles, R.F., von Winterfeldt, D., *Advances in Decision Analysis: From Foundations to Applications*. Cambridge University Press, New York, NY, 2007. Page 110, 113

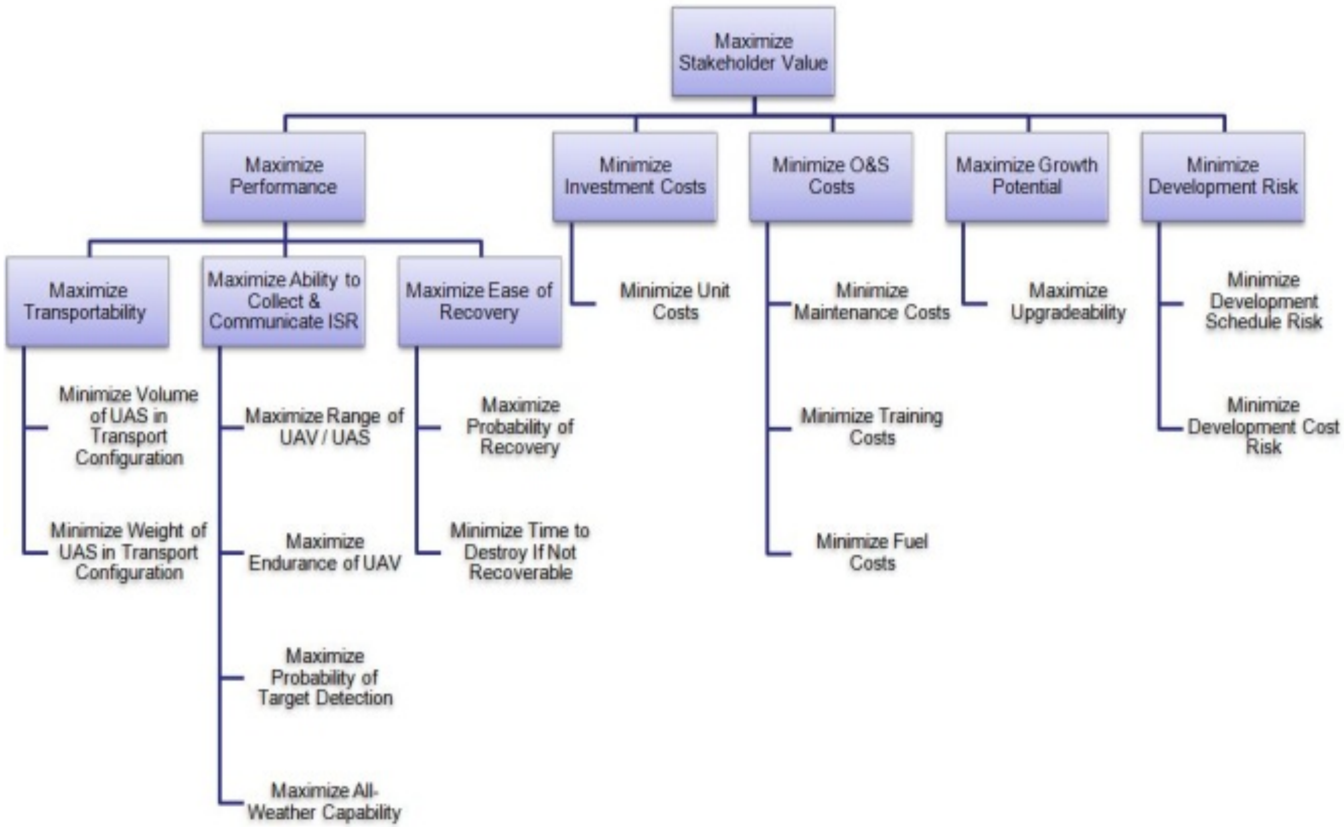
Developing Objectives & Measures – Identifying Broad Elements of Stakeholder Value

For systems engineering trade-off analyses, top-level stakeholder value often includes competing objectives of performance, development schedule, development cost, unit cost, support costs, and long term viability



Developing Objectives & Measures – Creating an Objectives Hierarchy

A Fundamental Objectives Hierarchy clearly describes fundamental objectives and associated sub-objectives.



Develop Objectives and Measures – Test Initial Set of Fundamental Objectives

Testing the initial set of fundamental objectives for key properties is an important task that helps ensure high quality decision making.

Set of Fundamental Objectives

Fundamental Objective 1
- ✓ Essential?[1]
- ✓ Controllable?[1]

Fundamental Objective 2
- ✓ Essential?[1]
- ✓ Controllable?[1]

• • •

Fundamental Objective N
- ✓ Essential?[1]
- ✓ Controllable?[1]

- ✓ Complete?[1]
- ✓ Non-redundant?[1]
- ✓ Concise?[1]
- ✓ Specific?[1]
- ✓ Understandable?[1]
- ✓ Preferentially Independent?[2]

[1] Edwards, W., Miles, R.F., von Winterfeldt, D., *Advances in Decision Analysis: From Foundations to Applications*. Cambridge University Press, New York, NY, 2007. Page 110, 113

[2] Kirkwood, C. W., 1997. *Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets.* Duxbury Press. (Belmont, CA).

Develop Objectives and Measures – Establishing High Quality Measures

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For each fundamental objective, a measure (also known as attribute, criterion, and metric) must be established so that alternatives that more fully satisfy the objective receive a better score on the measure than those alternatives that satisfy the objective to a lesser degree.

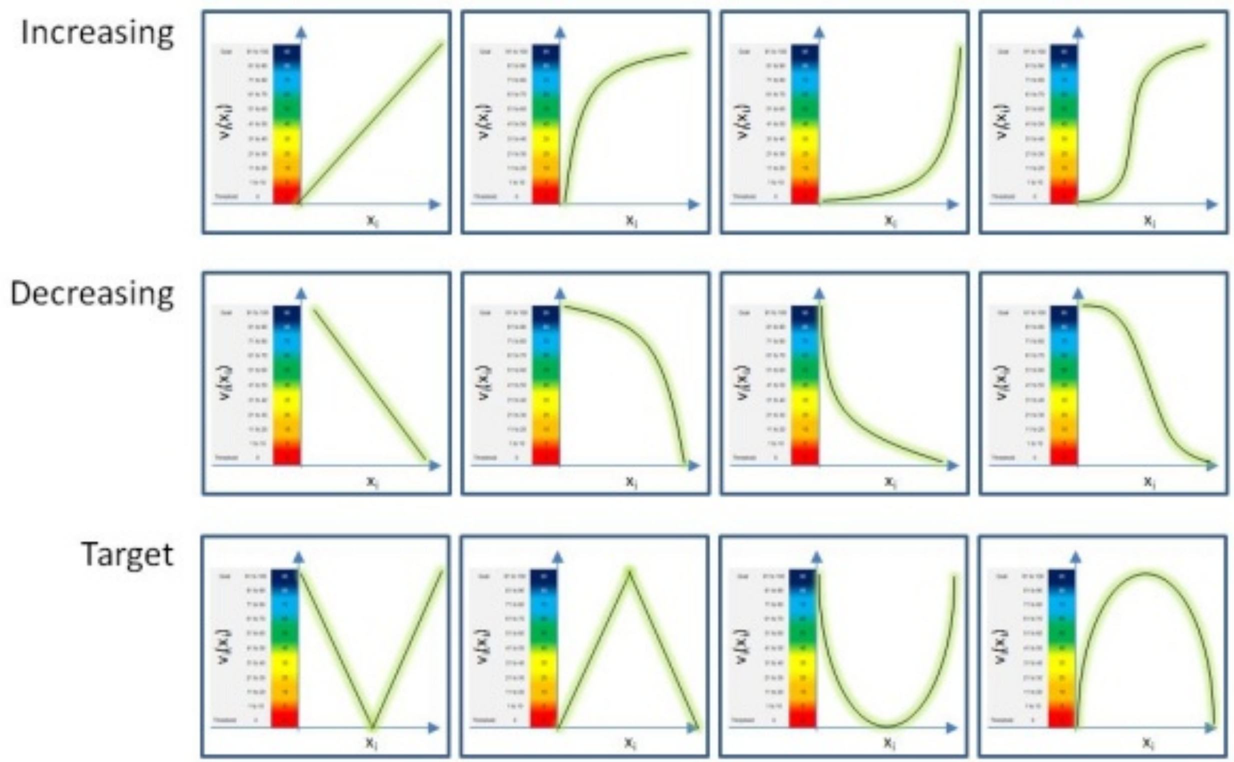
Preferred		When Natural Measure Not Available		When Constructed Measure Not Practical
Natural Measure	→	Constructed Measure	→	Proxy Measure

	Property	Definition
✓	Unambiguous	A clear relationship exists between consequences and descriptions of consequences using the measure.
✓	Comprehensive	The attribute levels cover the range of possible consequences for the corresponding objective, and value judgments implicit in the attribute are reasonable.
✓	Direct	The measure levels directly describe the consequences of interest.
✓	Operational	In practice, information to describe consequences can be obtained and value trade-offs can reasonably be made.
✓	Understandable	Consequences and value trade-offs made using the measure can readily be understood and clearly communicated.

(Keeney & Gregory 2005)

Developing Objectives & Measures – Constructing Value Functions

A defining feature of Multiobjective Decision Analysis (also called multiattribute value theory) is the transformation from measure space to value space that enables mathematical representation of a composite value score across multiple measures. This transformation is performed through the use of a value function. Value functions describe returns to scale on the measure.



Developing Objectives & Measures – Determine Weightings via Swing Weight Matrix

In an effort to capture the voice of the customer, system engineers will often ask a stakeholder focus group to prioritize their requirements. The mathematics of Multiobjective Decision Analysis (MODA) requires that the weights depend on importance of the preferentially independent measure and the range of the measure (walk away to stretch goal or ideal). A useful tool for determining weightings is the swing weight matrix.

Swing Weight Matrix	Level of Importance: Defining Capability	Level of Importance: Critical Capability	Level of Importance: Enabling / Enhancing Capability
Differentiation in Measure Range: High Differentiation	A	B2	C3
Differentiation in Measure Range: Moderate Differentiation	B1	C2	D2
Differentiation in Measure Range: Low Differentiation	C1	D1	E

Required Relationships
A > all other cells
B1 > C1, C2, D1, D2, E
B2 > C2, C3, D1, D2, E
C1 > D1, E
C2 > D2, E
D1 > E
D2 > E

Reference: Parnell, Gregory S., Driscoll, Patrick J., Henderson, Dale L., *Decision Making In Systems Engineering and Management, 2011, 2nd Edition*. John Wiley & Sons, Inc. Hoboken, NJ 2011.

Developing Objectives & Measures
Documenting Value Scheme with Rationale

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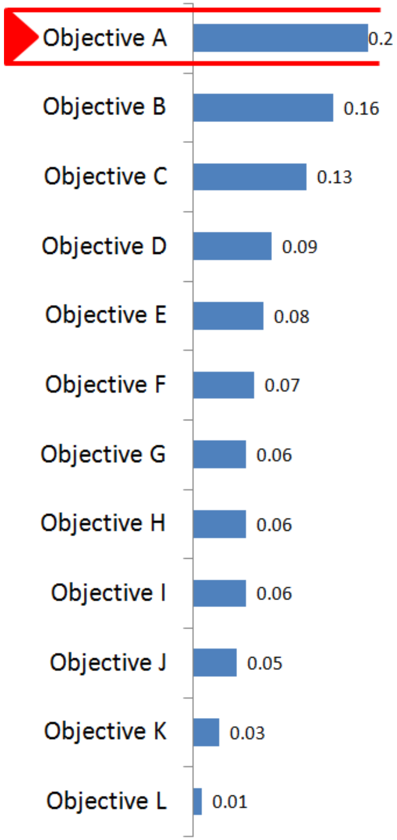
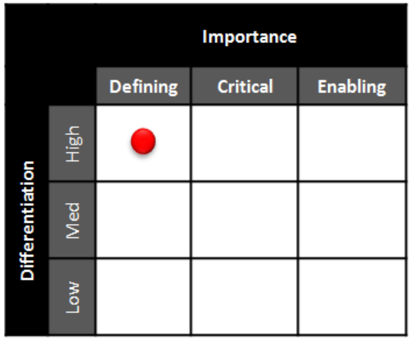
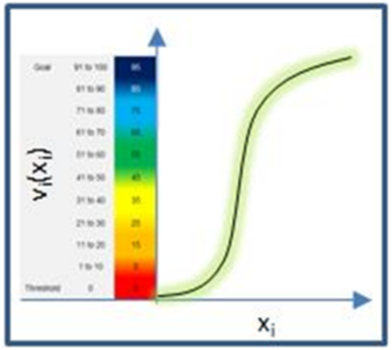
Beyond these best practices, the creation of a value scheme is as much an art as it is a science. This part of the decision analysis process clearly involves subjectivity. It is important to note however, that a subjective process is not synonymous with an arbitrary or capricious process. All decisions involve elements of subjectivity, the distinctive feature of formal decision management process is that these subjective elements are rigorously documented so that the consequences can be identified and assessed. Towards this end, it's considered good practice to document the how measured, the priority weighting, and the value function along with associated rationale for each fundamental objective.







How Measured:
For each fundamental objective, a measure must be established so that alternatives that more fully satisfy the objective receive a better score on the measure than those alternatives that satisfy the objective to a lesser degree. A measure (also known as attribute, criterion, and metric) must be unambiguous, comprehensive, direct, operational, and understandable. (Keeney & Gregory 2005). Use this space to fully describe the measure established for this objective.

Value Function:
A defining feature of Multiobjective Decision Analysis (also called multiattribute value theory) is the transformation from measure space to value space that enables mathematical representation of a composite value score across multiple measures. This transformation is performed through the use of a value function. Value functions describe returns to scale on the measure. Use this space to describe the key inflection points on the value function associated with this objective. Graphically portray value function and include on form as shown above.

- *Walk away*: stakeholder will dismiss alternative if it fails to meet at least this level, regardless of howl it performs along other objectives.
- *Marginally acceptable*: stakeholder begins to become interested and beyond this point perceived value increases rapidly.
- *Target* : usually maps to something resembling the threshold point identified in a draft CDD
- *Stretch goal:* improving beyond this point considered gold plating so there is very little available value between this point and meaningful limit.
- *Meaningful limit* : theoretical limit or known practice limit beyond which would be considered nonsense.

Priority Weighting:
The mathematics of Multiobjective Decision Analysis (MODA) requires that the weights depend on importance of the preferentially independent measure and the range of the measure (walk away to stretch goal or ideal). A useful tool for determining weightings is the swing weight matrix. For each measure, consider its importance by determining if the measure corresponds to a defining capability, a critical capability, or an enabling capability and also consider the variation measure range by considering the gap between the current capability and the desired capability and mark the appropriate cell of the matrix (as shown above) and provide rationale for importance and differentiation determination below. Consider showing weighting of measure of interest in bar chart form as shown in left part of form.

- *Importance*: xxxxx
- *Differentiation*: xxxxx

Generating & Defining Alternatives

A well structured trade analysis establishes a generic product structure and then, for each alternative, identifies the specific tech alternative selected for each product structure element.

	Cardinal	Buzzard	Crow	Pigeon	Robin	Dove
						
Subsystem	Design Choice	Design Choice	Design Choice	Design Choice	Design Choice	Design Choice
Propulsion System	Electric 300W & Li P	Electric 300W w/ Li Ion	Electric 600W w/ Solar	Elect 600W w Fuel Cell	Piston Engine 2.5 HP	Piston Engine 4.0 HP
Fuel	NA	NA	NA	NA	JP-8	JP-8
Fuel Tank Capacity	NA	NA	NA	NA	5 liter	7 liter
Propeller	18" Rear	20" rear	22" rear	24" Front	26" Front	28" Front
Wing Configuration	5 ft, Conventional	6 ft, Canard	6 ft, Tandem Wing	7 ft, Three Surface	8 ft., Conventional	9 ft., Conventional
Fin Configuration	Twin Boom Conv.	Inverted V	V Tail	Conventional	H Tail	Cruciform
Actuators	Electromagnetic	Hydraulic	MEMS	Hydraulic	Hydraulic	Hydraulic
Fuselage X Section	12" Diameter	14" Diameter	16" Diameter	18" Diameter	20" Diameter	22" Diameter
Airframe Material	Graphite Epoxy	Graphite Epoxy	Aramid-epoxy	Boron-epoxy	Fiberglass-epoxy	Fiberglass-epoxy
Avionics Arch.	Simplex	Simplex	Triplex	Triplex	Triplex	Triplex
Navigation Sensor	MEMS GPS / INS	MEMS GPS / INS	MEMS GPS / INS	MEMS GPS / INS	MEMS GPS / INS	MEMS GPS / INS
External Comms	LOS COMM Link	LOS COMM Link	LOS + SATCOM Link	LOS + SATCOM Link	LOS + SATCOM Link	LOS + SATCOM Link
Internal Comms	MIL-STD-1553B	MIL-STD-1553B	MIL-STD-1553B	MIL-STD-1553B	MIL-STD-1553B	MIL-STD-1553B
Autopilot	Pre-Programmed, Auto	Semi-Autonomous	Remotely Piloted	Pre-Programmed, Auto	Pre-Programmed, Auto	Pre-Programmed, Auto
Launch / Recovery	Hand / Belly	Hand / Belly	Hand / Belly	Hand / Belly	Hand / Belly	Hand / Belly
Acquisition Sensor	Un-cooled IR	Day Video	Day Video, Cooled IR	Day Video, Cooled IR	Day Video	SAR, Acoustic, Day, IR
Sensor Actuation	Pan-tilt	Pan-tilt-roll	Roll-tilt	Pan-tilt	Pan tilt	Pan tilt
Characteristics	Measurement	Measurement	Measurement	Measurement	Measurement	Measurement
Weight	5 lbs	10 lbs	10 lbs	15 lbs	30 lbs	40 lbs
Max Airspeed	60 kph	50 kph	80 kph	70 kph	60 kph	80 kph
Climb Rate	200 m / minute	150 m / minute	250 m / minute	200 m / minute	200 m / minute	250 m / minute

Assessing Alternatives Via Deterministic Analysis - Consequence Scorecard

Subject matter experts equipped with models (mathematical, physics, cost, etc.) assess each alternative against each objective. Assessments captured in consequence scorecard. Each column represents a measure and each row represents a particular alternative.

Raw Scorecard (expected pefromance values)			RELOCATE UAV		EMPLOY UAV				RECOVER UAV		GROWTH POT.	UNIT COST	DEVELOPMENT RISK		OPERATION & SUPPORT COST		
			Minimize UAV weight	Minimize UAV volume	Maximize all weather capability	Maximize UAV range	Maximize UAV probability of detection	Maximize UAV endurance	Maximize probability of recovery	Minimize time to destroy if not recoverable	Maximize upgradability	Minimize unit cost	Minimize development schedule risk	Minimize development cost risk	Minimize training cost	Minimize maintenance cost	Minimize fuel cost
ID	Name	Image	(lbs)	ft3	index	km	P[D]	hours	P[R]	sec	index	FY13$K	index	index	FY13$	FY13$	FY13$
1	Cardinal		5	12	3	10	0.92	0.5	0.6	1	0.3	250	0.9	0.9	300	300	0
2	Buzzard		10	15	1	10	0.9	1	0.7	2	0.6	300	0.8	0.8	300	300	0
3	Crow		10	20	3	70	0.92	1	0.8	2	0.6	350	0.7	0.7	300	300	0
4	Pigeon		15	30	3	80	0.92	1.5	0.9	2	0.6	400	0.6	0.6	300	300	0
5	Robin		30	40	1	90	0.9	2	0.9	2	0.6	500	0.5	0.5	500	500	300
6	Dove		40	50	5	100	0.94	2	0.9	3	0.9	700	0.4	0.4	500	500	500
7	Ideal		5	10	5	100	1	2	0.9	1	1	200	1	1	250	0	0

Synthesizing Results - Value Scorecard

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Transforming consequence scorecard into a value scorecard is accomplished through the use of the value functions. In an effort to enhance speed & depth of comprehension, increments on the value scale are associated with a color according to heat map conventions

Heat-indexed Value Scorecard			RELOCATE UAV		EMPLOY UAV				RECOVER UAV		GROWTH POT.	UNIT COST	DEVELOPMENT RISK		OPERATION & SUPPORT COST		
			Minimize UAV weight	Minimize UAV volume	Maximize all weather capability	Maximize UAV range	Maximize UAV probability of detection	Maximize UAV endurance	Maximize probability of recovery	Minimize time to destroy if not recoverable	Maximize upgradability	Minimize unit cost	Minimize development schedule risk	Minimize development cost risk	Minimize training cost	Minimize maintenance cost	Minimize fuel cost
ID	Name	Image	0.06	0.11	0.14	0.28	0.14	0.23	0.03	0.01	1	1	0.5	0.5	0.33	0.33	0.33
1	Cardinal		100	97	90	13	59	1	47	100	31	94	83	83	83	85	100
2	Buzzard		86	92	1	13	42	60	77	90	61	88	67	67	83	85	100
3	Crow		86	85	90	83	59	60	90	75	61	82	50	50	83	85	100
4	Pigeon		72	57	90	90	59	80	100	75	61	76	34	34	83	85	100
5	Robin		29	29	1	95	42	100	100	60	61	56	18	18	17	67	51
6	Dove		1	1	100	100	75	100	100	1	91	1	1	1	17	67	18
7	Ideal		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Synthesizing Results – Additive Value Model

The first step in assessing an alternative's aggregated value is a prescreen for alternatives that fail to meet a walk-away point for any objective measure and set that alternative's aggregated value to zero regardless of how it performance on other objective measures. For those alternatives that pass the walk-away prescreen, the additive value model uses this equation to calculate each alternative's aggregated value:

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i)$$

where

v(x) is the alternative's value,

i = 1 to n is the number of the measure,

x_i is the alternative's score on the i^{th} measure,

$v_i(x_i)$ = is the single dimensional value of a score of x_i,

w_i is the weight of the i^{th} measure,

$$\sum_{i=1}^{n} w_i = 1$$

and (all weights sum to one).

The additive model assumes preferential independence. See Keeney & Raiffa, 1976, and Kirkwood, 1997 for additional models.

Synthesizing Results – Value Component Graph

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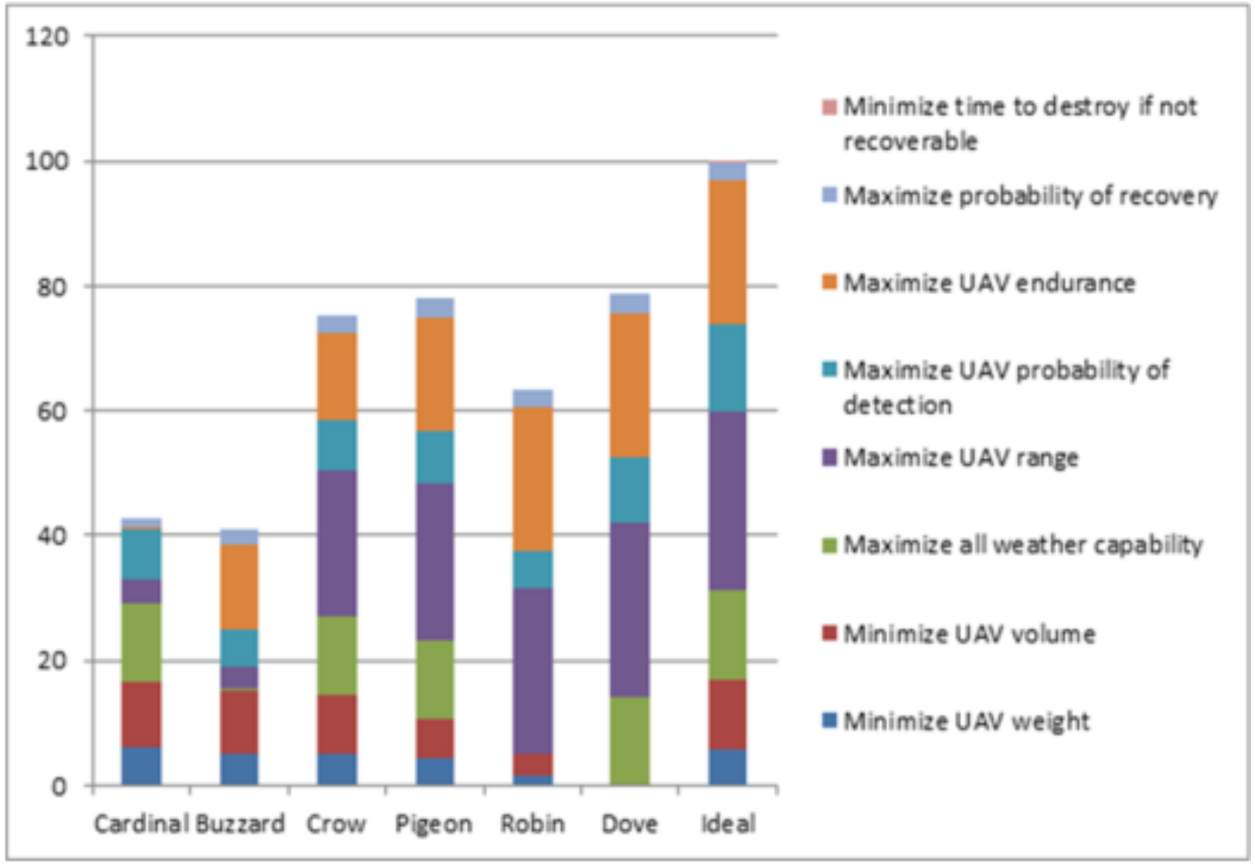
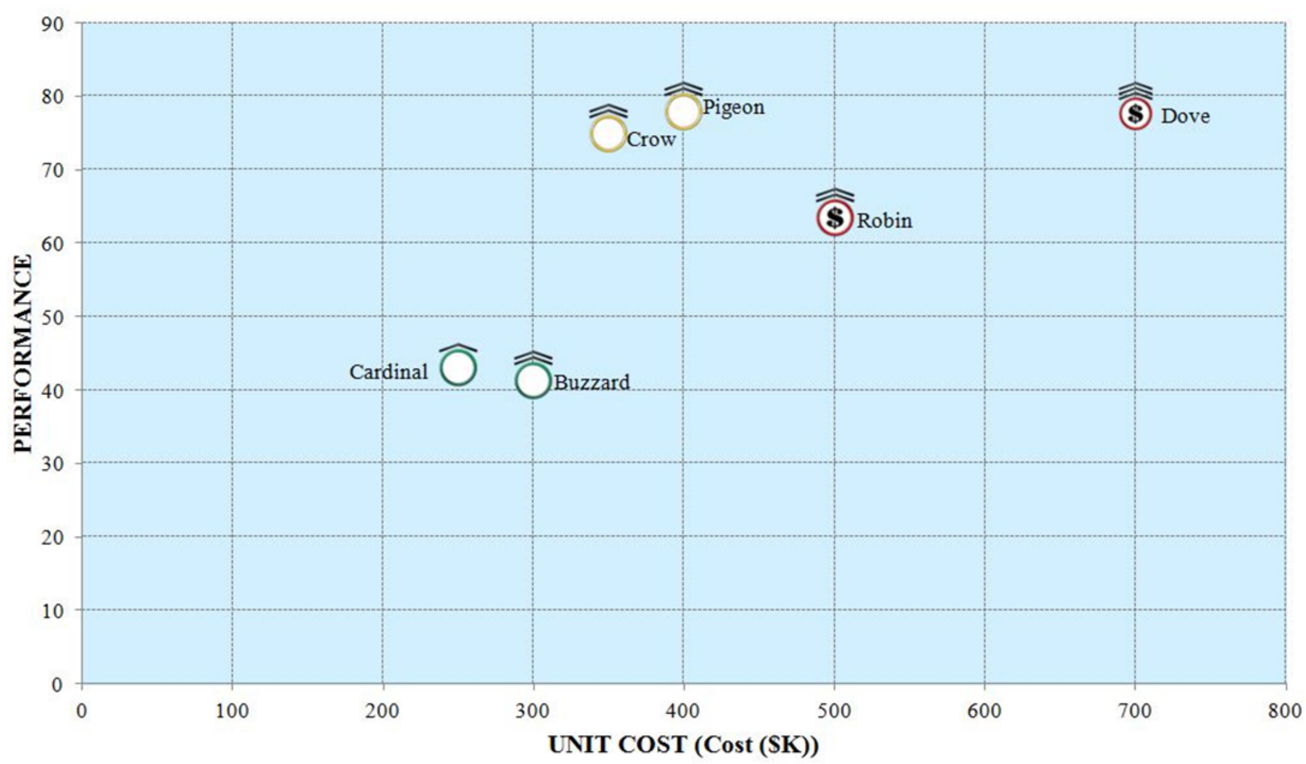
A popular aggregated visualization is the value component graph. In a value component graph, each alternative's total value is represented by the total length of a segmented bar. Each bar segment represents the contribution of the value earned by the alternative within a given measure by the weighted value



Synthesizing Results – Value Scatterplot

The stakeholder value scatterplot shows in one chart how all system level alternatives respond in multiple dimensions of stakeholder value.

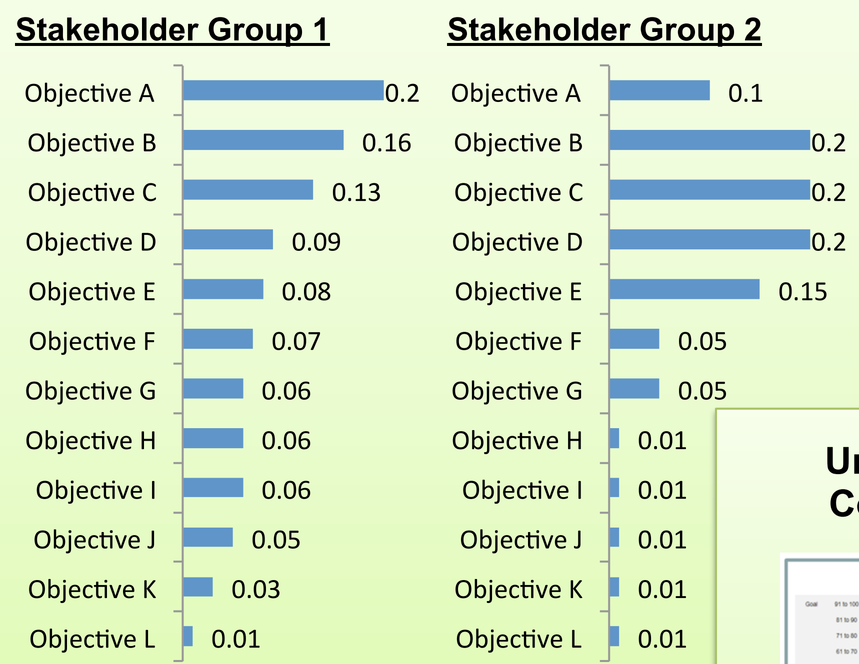
Example shows how the six hypothetical UAV alternatives respond to five dimensions of stakeholder value - unit cost, performance, development schedule, growth potential, and operation and support costs. Each system alternative is represented by a scatterplot marker. An alternative's unit cost and performance value are indicated by a marker's x and y position respectively. An alternative's development risk is indicated by the color of the circle (green-low, yellow-medium, red-high) while the degree of growth potential for a particular alternative is shown as the number of hats above the circular marker (1 hat – low growth, 2 hats – moderate growth, 3 hats – high growth). Figure 9 depicts an alternative with high operating and support (O&S) costs with a red dollar sign appearing inside the marker. An alternative with moderate or low O&S costs would appear with a black dollar sign or no dollar sign respectively



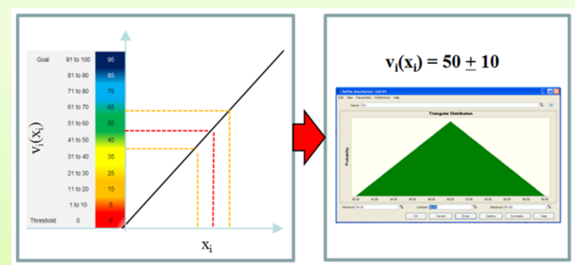
Identifying Uncertainty

Uncertainty in new product development efforts often surround assumptions regarding measure weightings and surrounding single dimensional consequence estimates. It is important to capture and discuss these uncertainties and assess impact in the next step of the process.

Uncertainty Surrounding Priorities



Uncertainty Surrounding Consequence Estimates



Assessing Impact of Uncertainty

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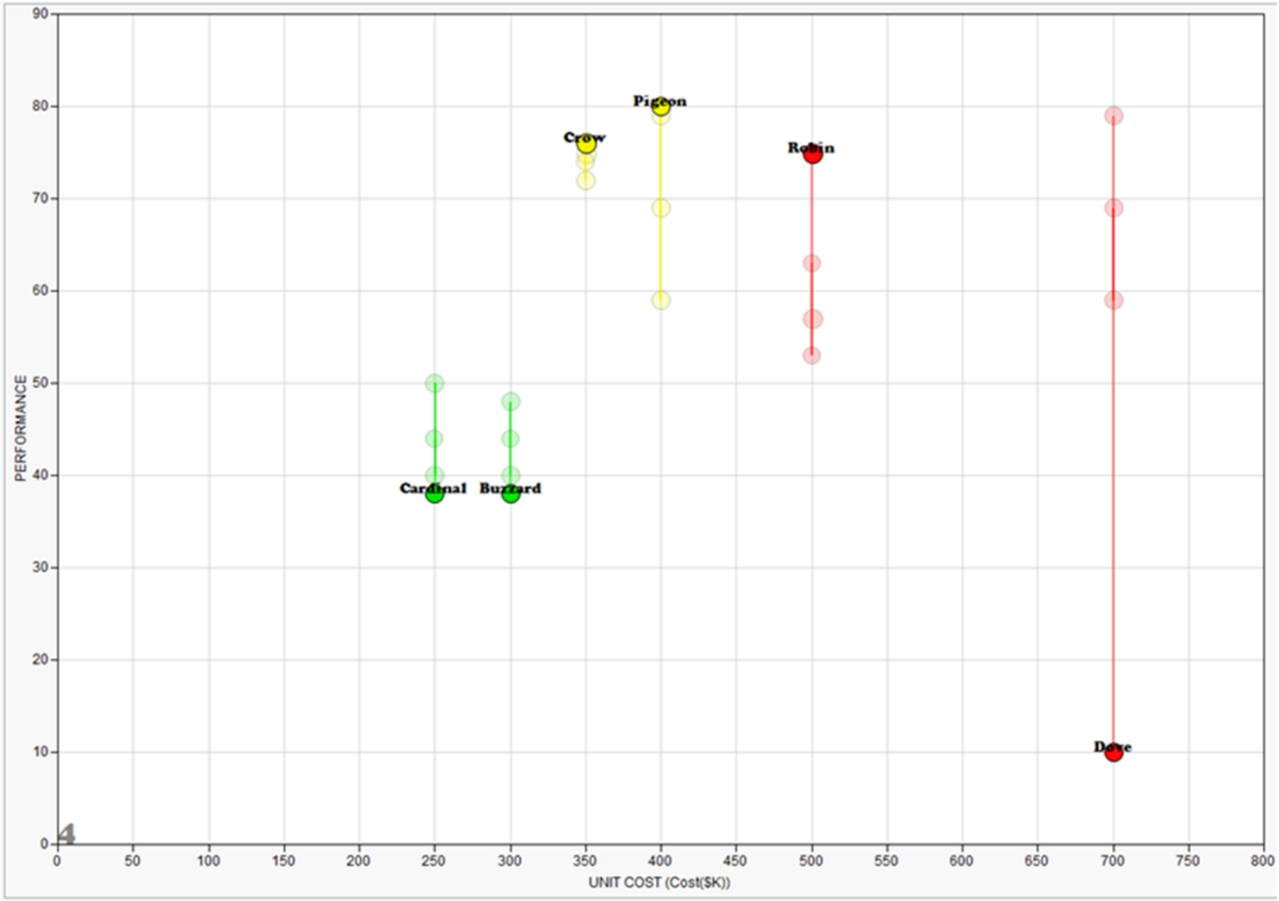
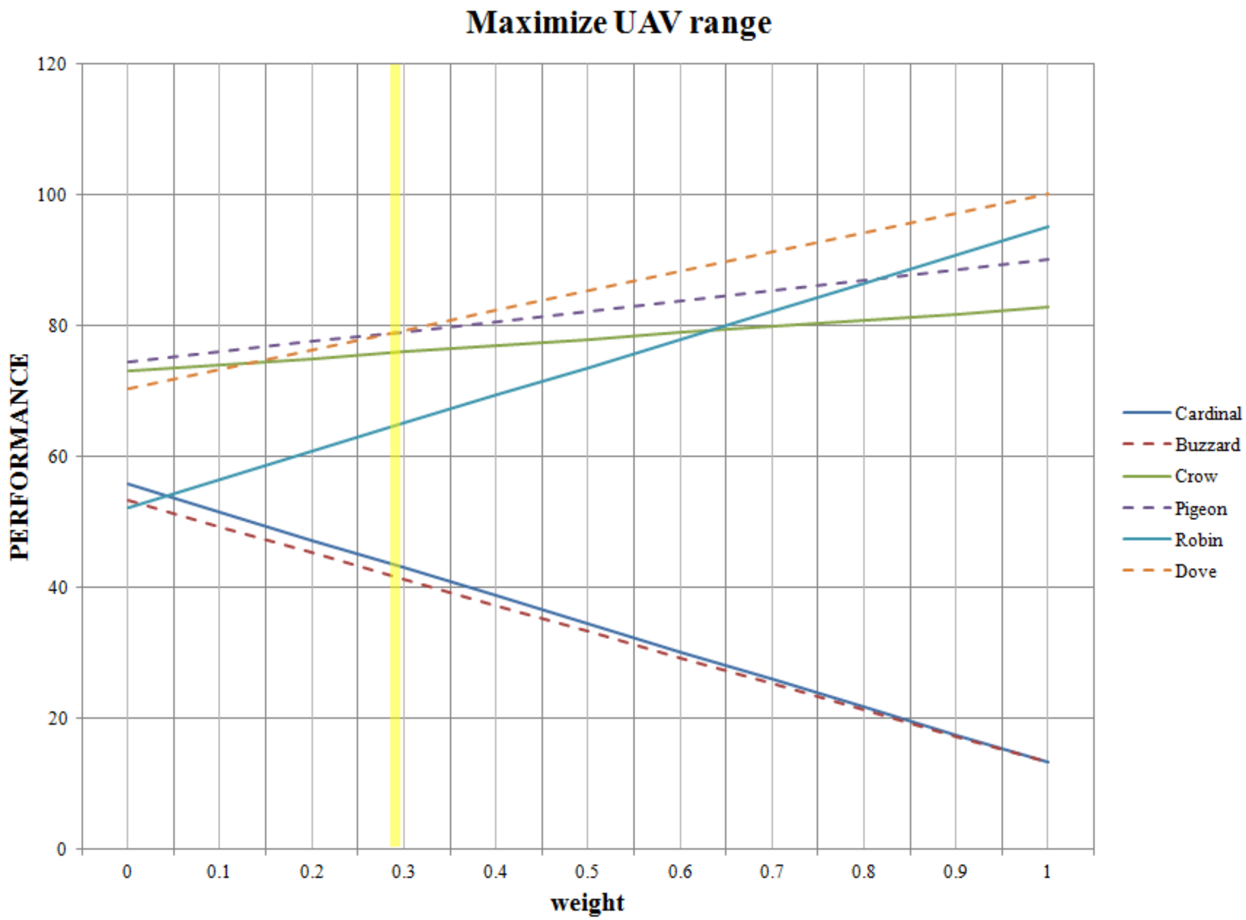
Sensitivity analysis allows decision makers to see how performance values for each alternative move as priority weightings change and/or as uncertainty surrounding single dimensional objective measure is incorporated. This allows the decision analyst to identify the uncertainties that impact the decision findings and the uncertainties that are inconsequential to decision findings.



Assessing Impact Of Uncertainty - Weight Sweep Line Graph

By sweeping each measure's weighting from absolute minimum to absolute maximum while holding the relative relationship between the other measure weightings constant and noting changes to overall score, one can visualize the impact a particular measure weighting has on overall value and answer questions regarding the degree to which a particular weighting would need to be changed in order to change recommended alternative.



Improving Alternatives

Mining the data generated for the first set of alternatives will likely reveal opportunities to modify some subsystem design choices to claim untapped value and reduce risk. Recall the cyclic decision analysis process map and the implied feedback. Taking advantage of this feedback loop and using initial findings to generate new and creative alternatives starts the process of transforming the decision process from "Alternative-Focused Thinking" to "Value-Focused Thinking" (Keeney 1992). To complete the transformation from alternative-focused thinking to value-focused thinking, consider taking additional steps to spark focused creativity to overcome anchoring biases. To help generate a creative and comprehensive set of alternatives, consider conducting an alternative generation table (also called a morphological box).

Morphological Box

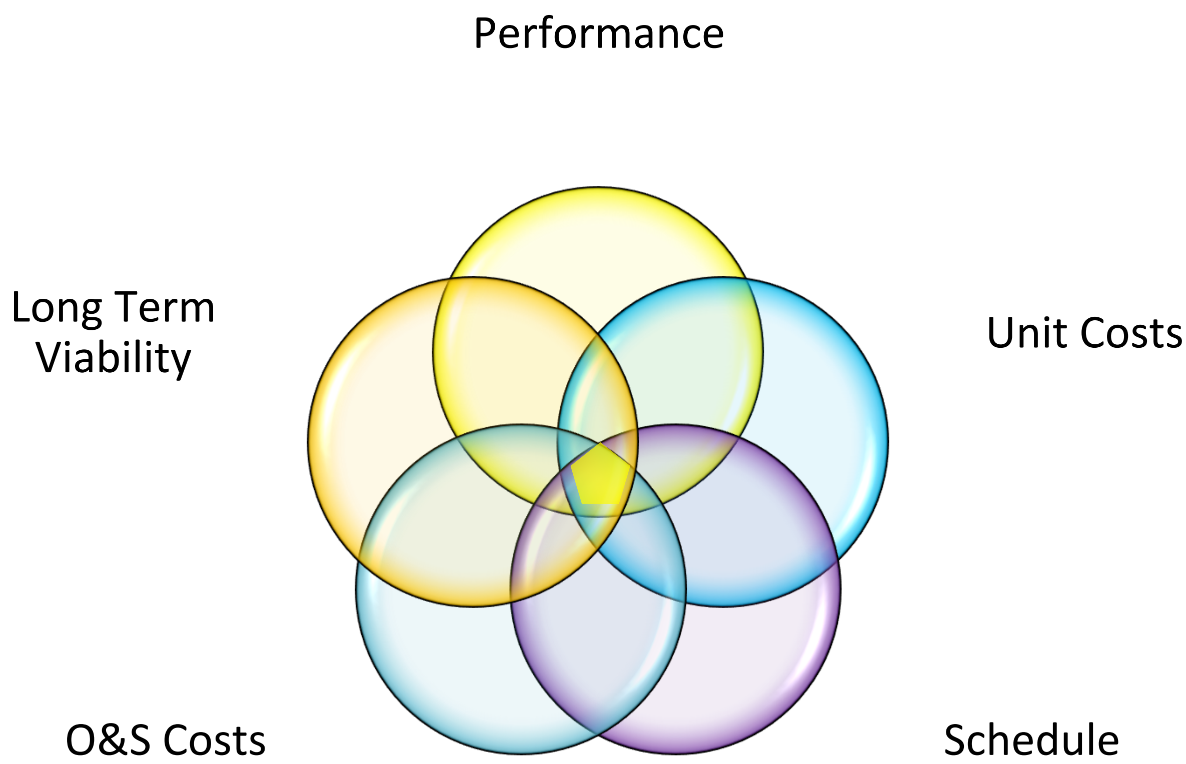
Top Level Function of System

	Sub-function 1	Sub-function 2	Sub-function 3	Sub-function 4	Sub-function 5	Sub-function 6	Sub-function 7
Generic Physical Component	**Component 1**	**Component 2**	**Component 3**	**Component 4**	**Component 5**	**Component 6**	**Component 7**
Design Decisions	A B C D	E F	G H I F	J K L	M N	O P	Q R S

*Reference: Buede, Dennis M., The Engineering Design of Systems. John Wiley & Sons, Inc. Hoboken, NJ 2000.

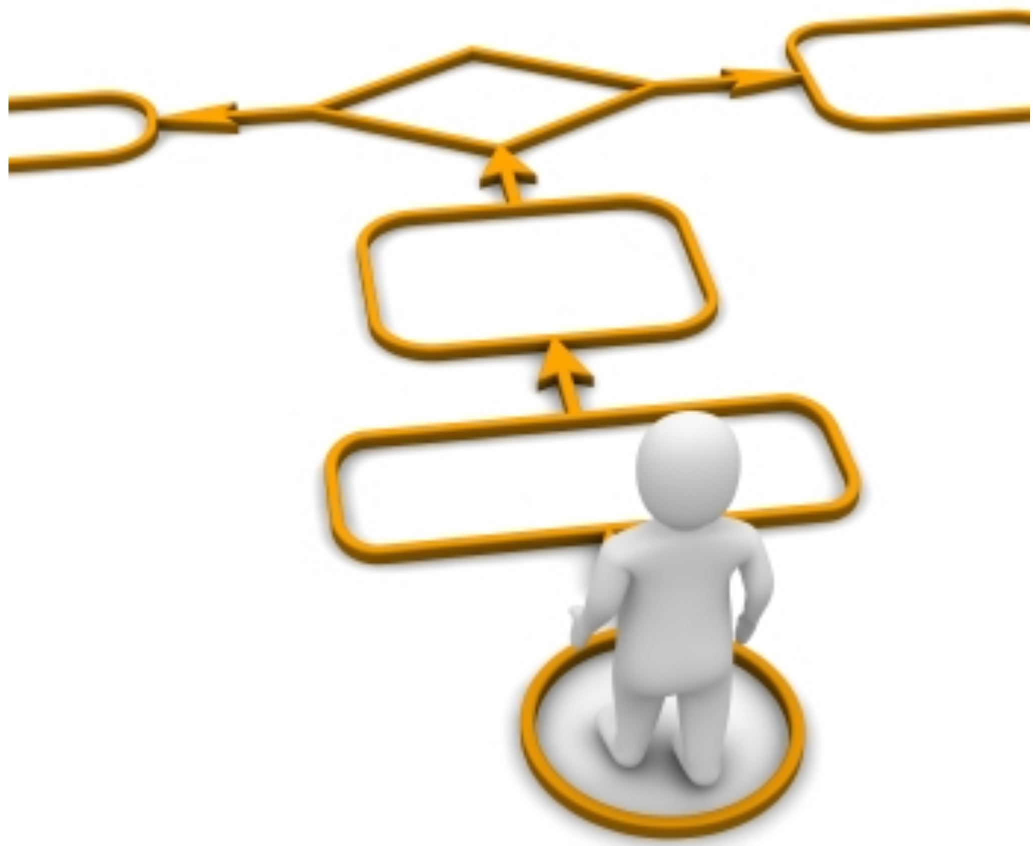
Communicating Tradeoffs

This is the point in the process where the decision team identifies key observations regarding what stakeholders seem to want and what they must be willing to give up in order achieve it. It is here where the decision team can highlight the design decisions that most influence shareholder and stakeholder value and which are inconsequential. In addition, the important uncertainties and risks should also be identified. Observations regarding combination effects of various design decisions are also important products of this process step. Competing objectives that are driving the trade should be explicitly highlighted as well



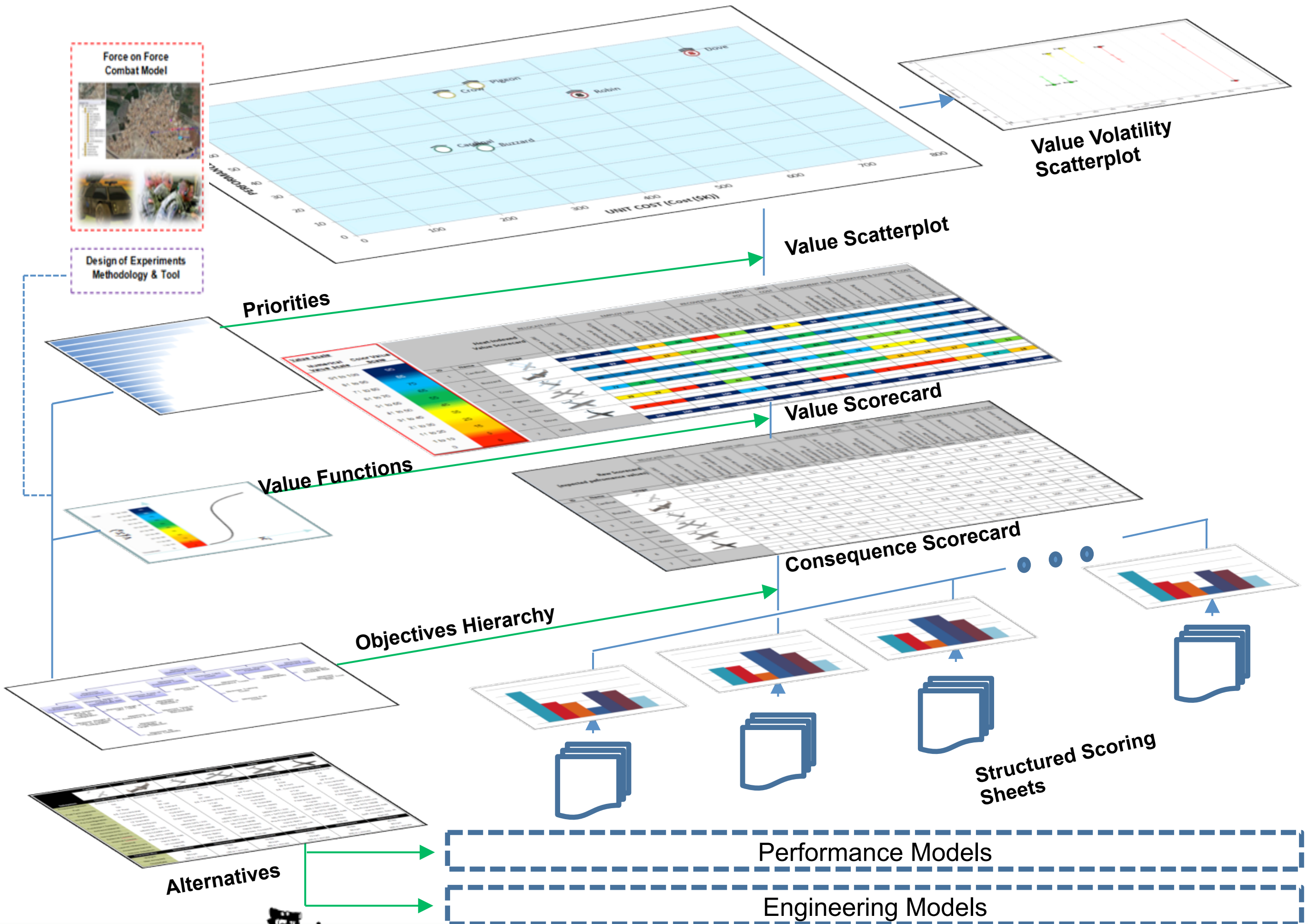
Presenting Recommendations

Describe the who, what, where, when, and how regarding decision implementation. Where is the next decision point?



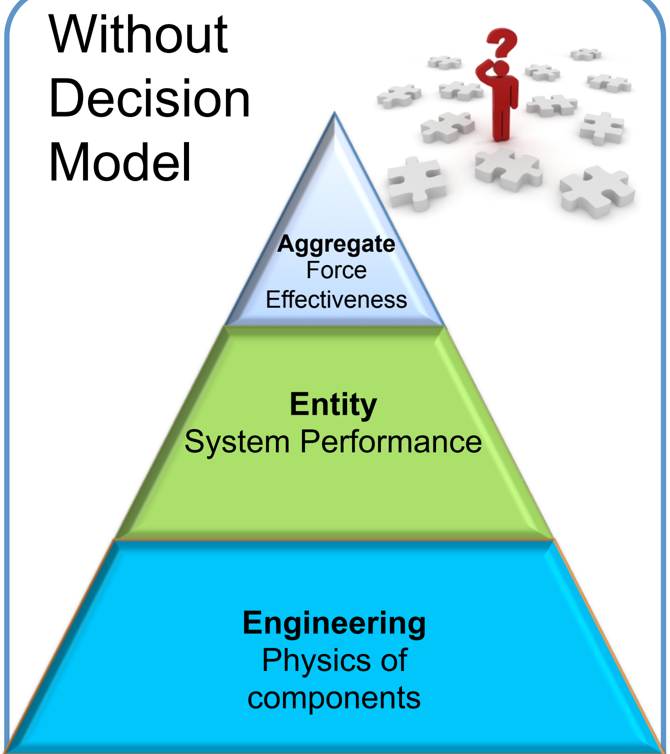
Decision Support Model Construct

A decision model integrates outputs of otherwise separate models into a holistic system view mapping critical design choices to consequences relevant to stakeholders helping those executing the systems engineering tradeoff analysis overcome cognitive limits without oversimplifying the problem.

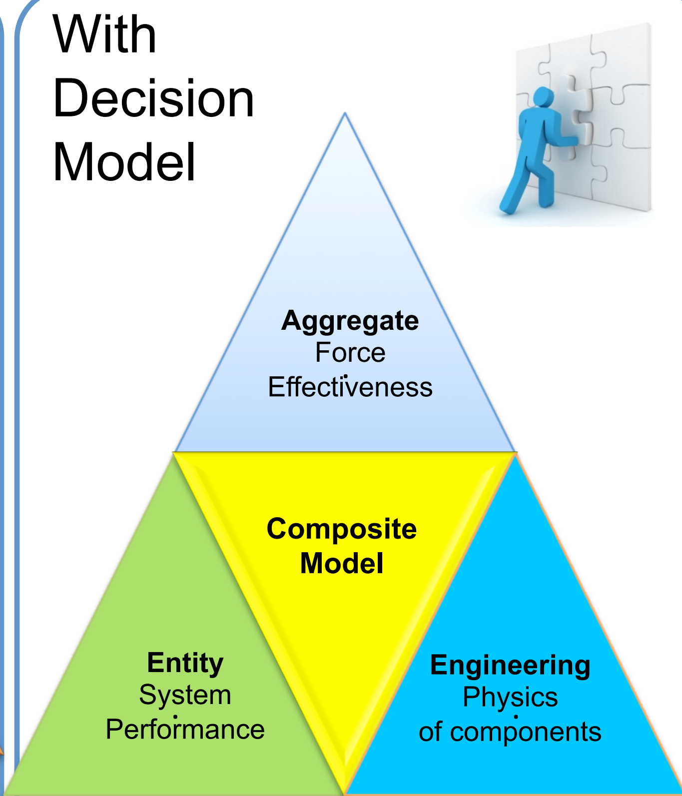


The Role of a Composite Model (Decision Support Model)

A composite model integrates outputs of otherwise separate models into a holistic system view mapping critical design choices to consequences relevant to stakeholders. A decision support model helps decision maker (and those executing the systems engineering tradeoff analysis) overcome cognitive limits without oversimplifying the problem.



Parnell, Gregory S., Driscoll, Patrick J., Henderson, Dale L., *Decision Making In Systems Engineering and Management – Second Edition.* John Wiley & Sons, Inc. Hoboken, NJ 2011.



Decision Centric Systems Engineering Process

Positioning decision making as central to all systems engineering activity helps ensure that SE efforts are rightfully interpreted as relevant and meaningful and thus maximize the discipline's value proposition to new product developers and their leadership.

High Quality Decisions Emerge From The Intersection of SE & Operations Research

INCOSE International Symposium
Las Vegas, NV
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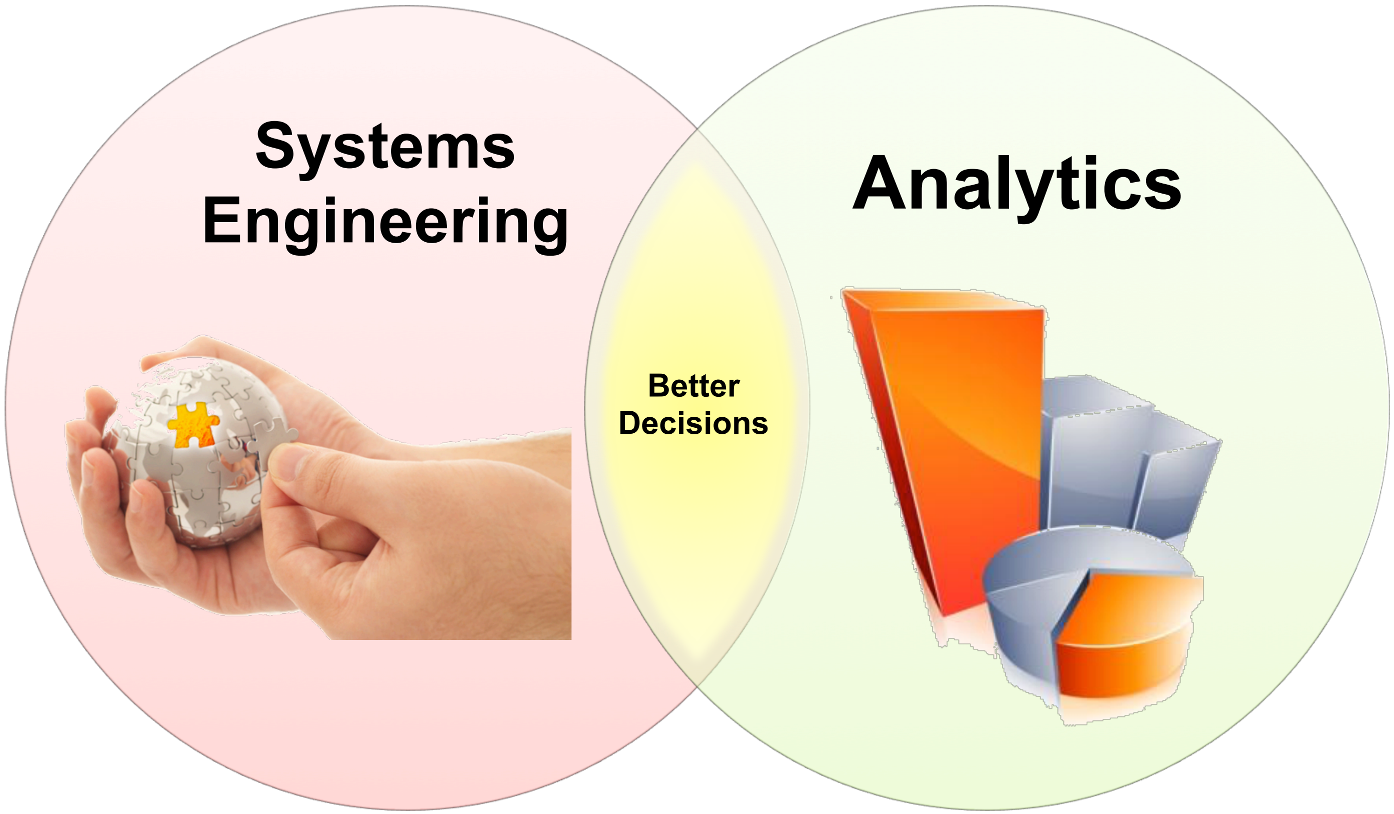
Many decisions encountered during new product development may benefit from the holistic perspective of the systems engineering discipline coupled with the reasoning tools emerging from the operations research community.



Thank You

Matthew V. Cilli
Systems Engineering PhD Candidate
Stevens Institute of Technology, Hoboken, NJ
mcilli@stevens.edu

Gregory S. Parnell
Visiting Professor of Industrial Engineering
4207 Bell Engineering Center,
Department of Industrial Engineering, University of Arkansas
gparnell@uark.edu