

Value Modeling and Multi-Objective Decision Analysis

Lecture 50, v01

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BSEE

MSSE

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Decision Analysis

- Successful systems engineering requires sound decision making
- Difficult because of
 - Multiple competing objectives
 - Numerous stakeholders
 - Substantial uncertainty
 - Significant consequences
 - High accountability
- This requires a formal decision management process
 - Provides a structured, analytical framework
 - For objectively identifying, characterizing and evaluating a set of alternatives
 - For a decision at any point in the life cycle
 - To select the most beneficial course of action

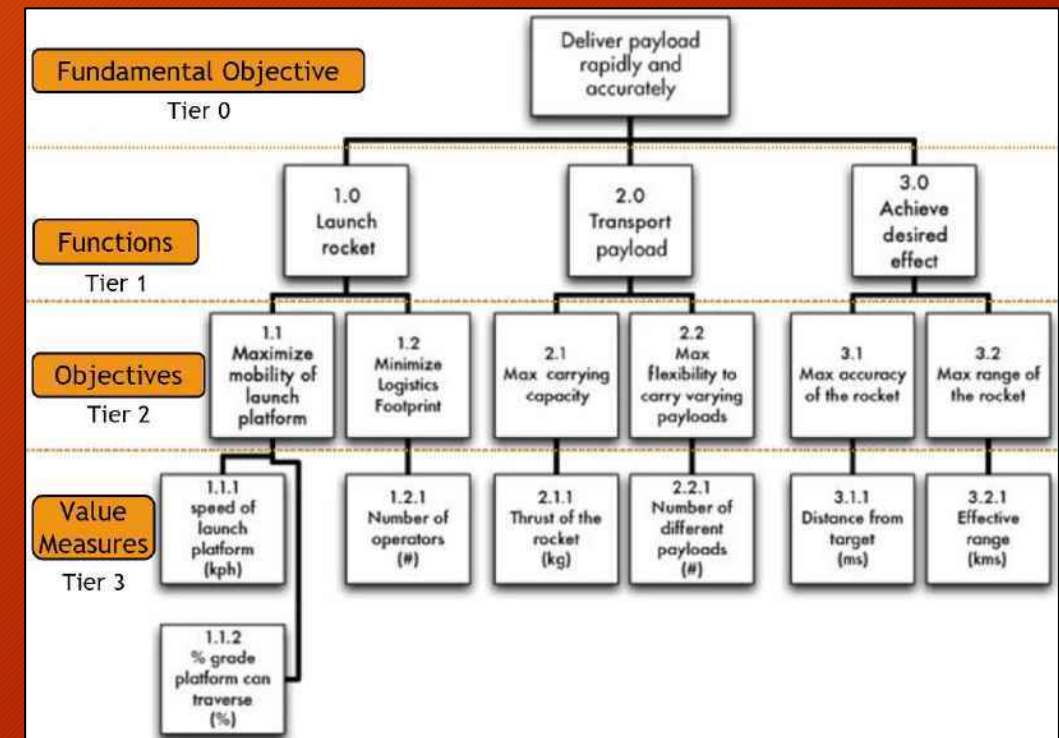
Value Modeling Overview

- *Value Modeling* provides a methodology for evaluating candidate solutions
- This evaluation methodology employs the concept of *Value-Focused Thinking*
- Value modeling enables us to develop a *Qualitative Value Model* that captures the most important functions and objectives for the system
- The qualitative value model is then used to build a *Quantitative Value Model*, which provides a measurable method to evaluate how well candidate solutions meet the *Fundamental Objective* of the systems decision problem
- The concepts of multiple objective decision analysis are then used to build the mathematical framework for the value model

Qualitative Value Models

- The qualitative value model is the most important because it reflects the key stakeholder values regarding the systems decision problem
 - If the qualitative model does not accurately capture these values, then the quantitative value model will not be useful in properly evaluating candidate solutions
- The qualitative value model, represented by all its objectives and value measures, must be sufficient in scope to evaluate the fundamental objective in the systems decision problem
- The functions or value measures on the same tier in the hierarchy should not overlap
- The value of the scores on one value measure should not depend on the scores on any of the other value measures
- A value hierarchy should contain as few measures as possible while being mutually exclusive (measures appear only once and can be treated separately) and collectively exhaustive (measures encompass all that the decision-maker values)

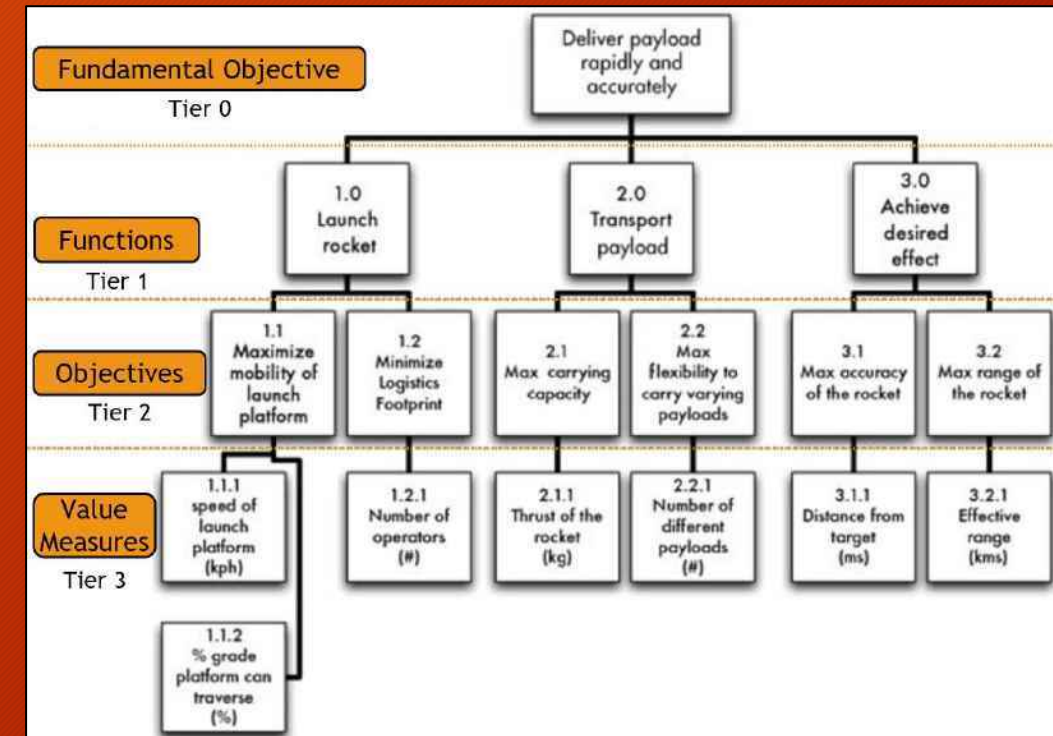
Example Qualitative Value Model for Simple Rocket System



Value Modeling Terminology

- Qualitative Value Model
 - The complete description of the stakeholder qualitative values, including the
 - Fundamental Objective
 - Functions (if used)
 - Objectives
 - Value Measures
- *Value Hierarchy* or *Value Tree*
 - Pictorial representation of the qualitative value model
- *Tier*
 - Levels in the value hierarchy
- *Fundamental Objective*
 - The most basic high level objective that stakeholders are trying to achieve
- *Functions*
 - The necessary and sufficient functions and their interactions required to meet the fundamental objective
- *Objectives*
 - Objectives for each function that define value
- *Value Measures*
 - The measures for each objective to assess the potential value

Example Value Hierarchy for Simple Rocket System



From "Decision Making In Systems Engineering And Management"

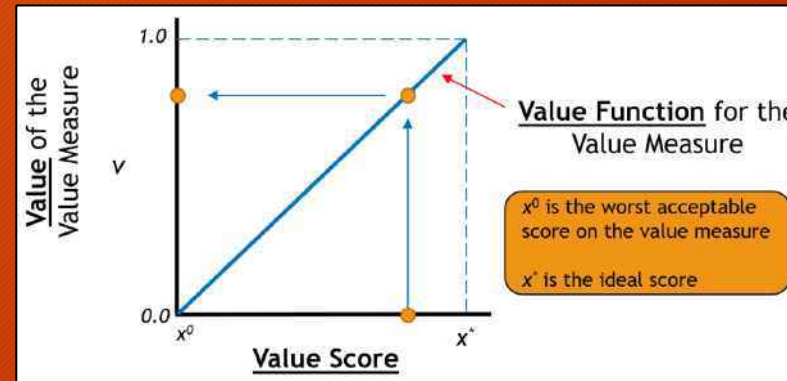
Value Modeling Terminology (continued)

- *Quantitative Value Model*

- The value functions, weights, and mathematical equation used to evaluate candidate solutions

- *Value Measure*

- A scale to assess how well an objective has been obtained, typical examples are
 - 0-100
 - 0-10
 - 0-1 (used in example to the right)
- Alternate terms for Value Measure include:
 - Evaluation Measures
 - Measures of Effectiveness
 - Performance Measures
 - Metrics



- *Score*

- A number in the range of the value measure that reflects the estimated future performance of a candidate solution

- *Value Function*

- A function that assigns value to a value measure's score
- A value function measures returns to scale over the range of the value measure

Value Modeling Terminology (continued)

- **Weights**

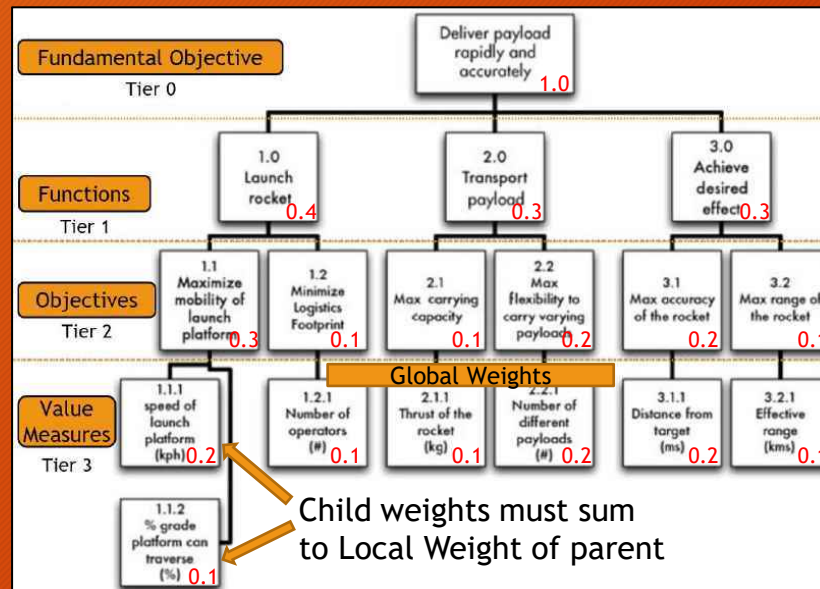
- The weight assigned to a value measure reflects the measure's importance and the range of its measurement scale. We assess swing weights by assessing the impact of “swinging” the value measure from its worst to its best level

- **Global (Measure) Weights**

- The measure weights for each value measure
- Global (measure) weights sum to 1

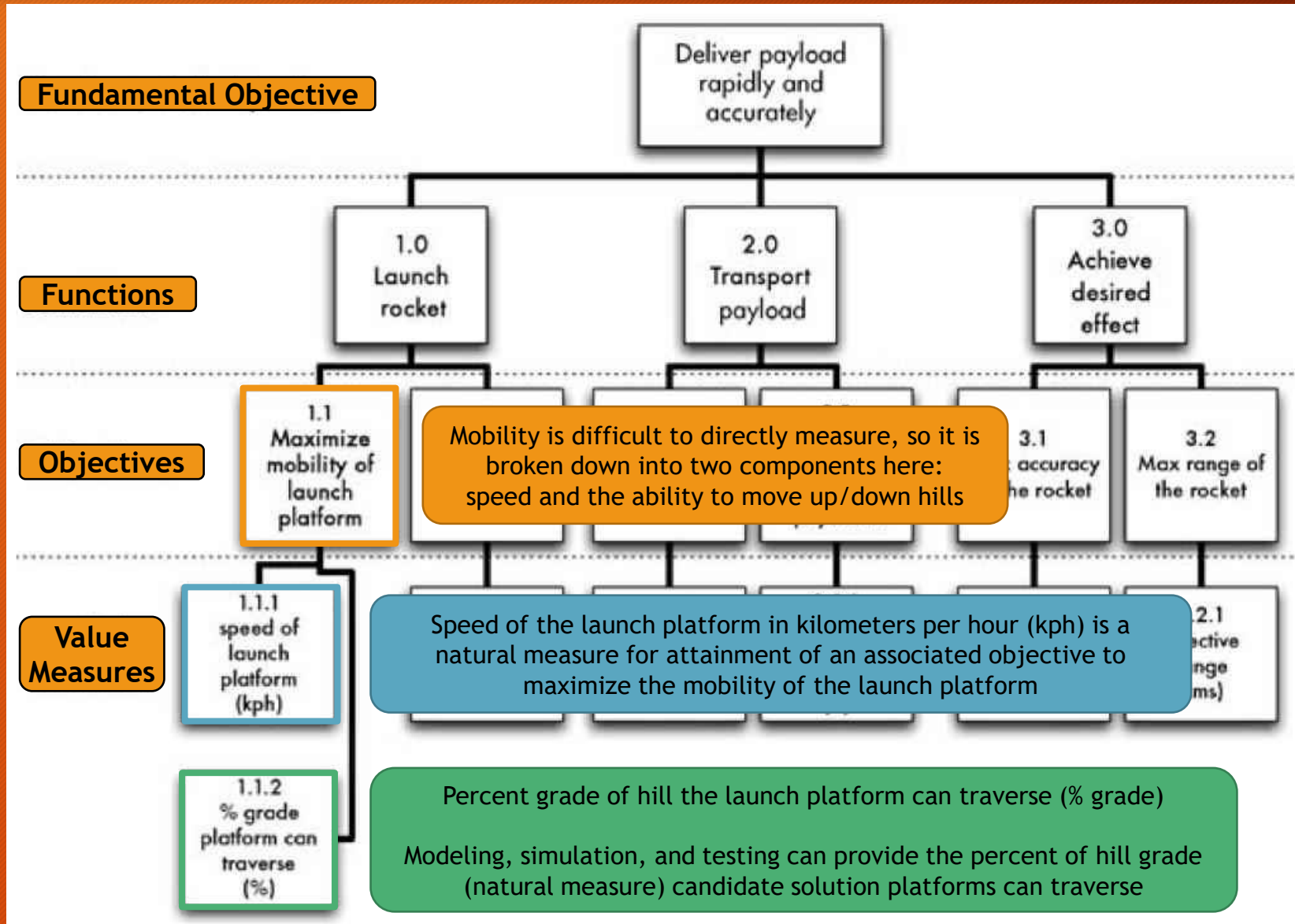
- **Local Weights**

- The weights at each node in the value hierarchy
- Local weights below each node sum to 1

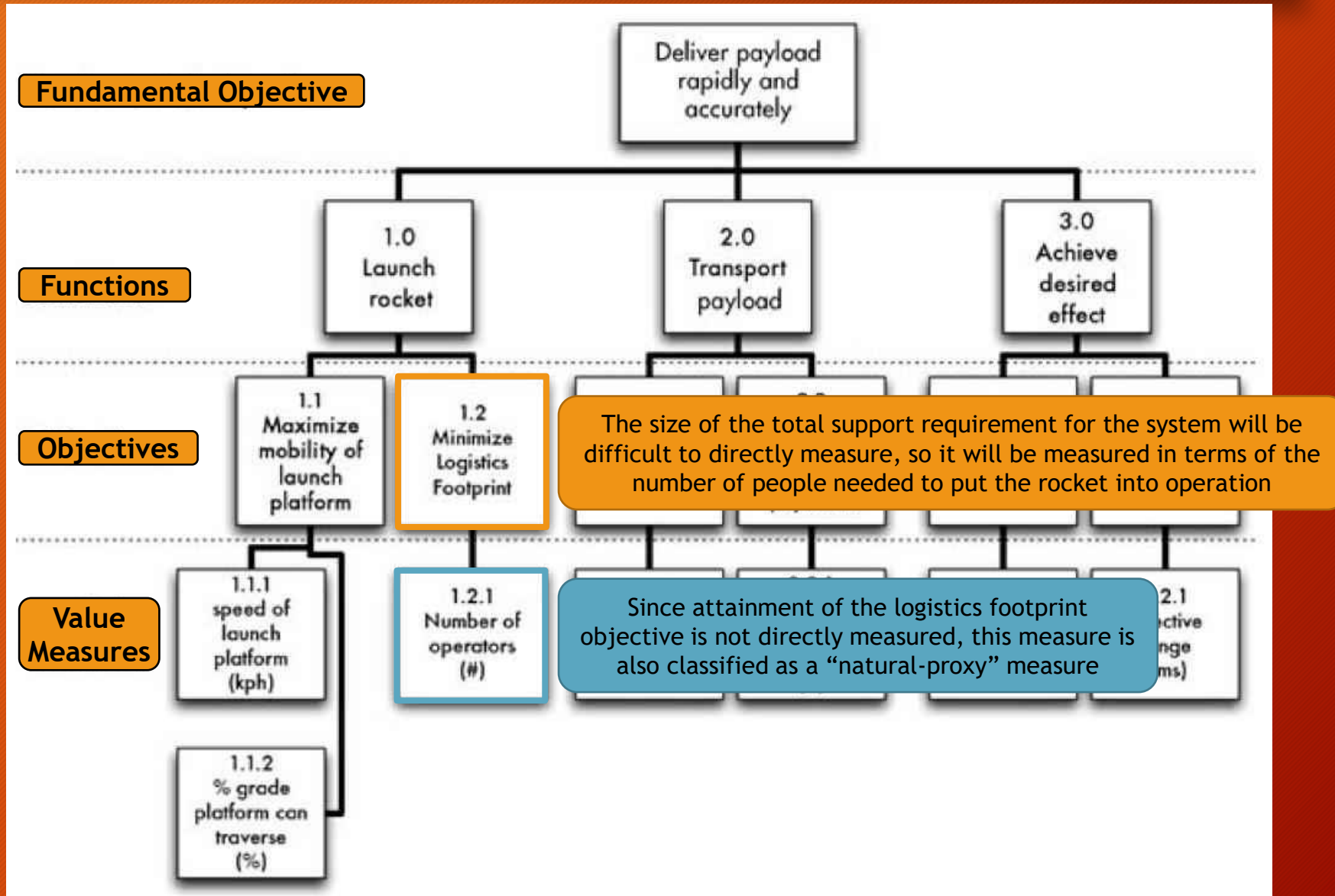


From "Decision Making In Systems Engineering And Management"

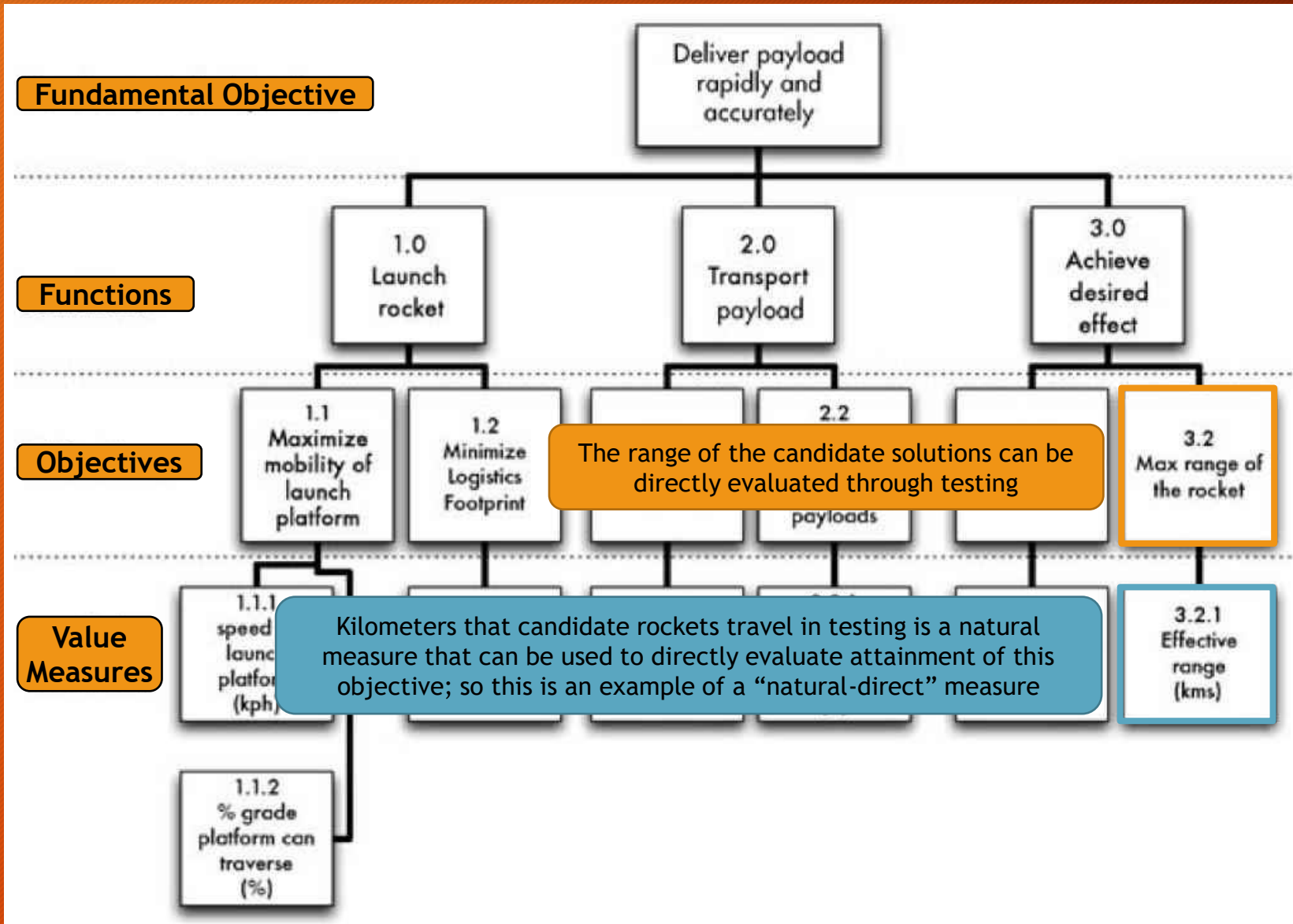
Example Value Hierarchy



Example Value Hierarchy



Example Value Hierarchy



Process for Creating a Qualitative Value Model

1. Identify the Fundamental Objective

- a. This is a clear, concise statement of the primary reason the decision problem is being undertaken

2. Identify Functions that Provide Value

- a. For many systems, the functional hierarchy provides a basis for the value hierarchy

3. Identify the Objectives that Define Value

- a. An objective provides a statement of preference
- b. Example: “maximize efficiency” or “minimize time”

4. Identify the Value Measures

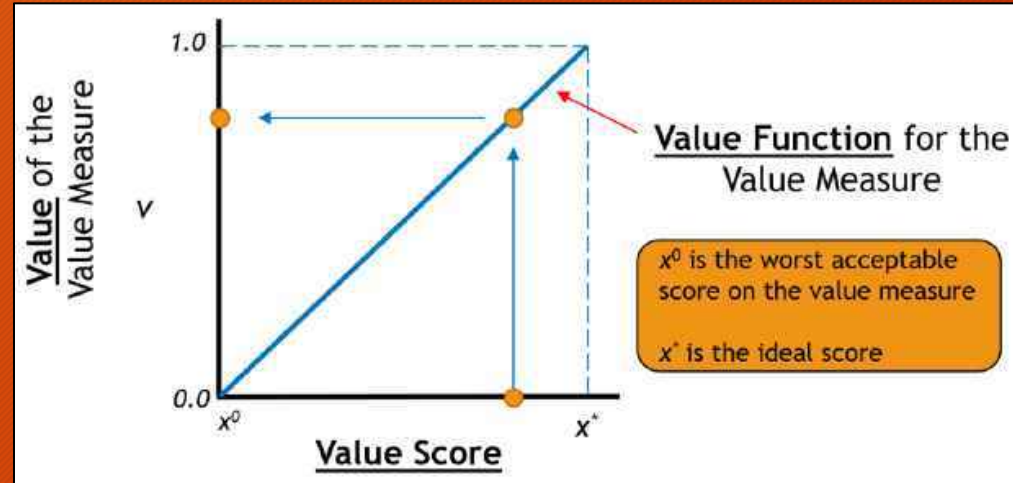
- a. Value measures are the same as Measures of Effectiveness (MOEs)
- b. Value measures tell how well a candidate solution attains an objective
- c. Value measures are developed based on their alignment with the objective and their scale of measurement
- d. Value measures are either
 - i. Direct (can directly measure attainment of an objective)
 - ii. Proxy (measures attainment of an associated objective)
- e. Now, build a value hierarchy

5. Discuss the Value Model with the Key Stakeholders

- a. It is very important to get approval of the value model from the key stakeholders
- b. This will ensure that future system development efforts are on track

Quantitative Value Models

- Quantitative value modeling helps determine how well candidate solutions to a systems decision problem attain the stakeholder values
- A mathematical model will be developed to assess the values of candidate solutions
- The emphasis for our quantitative value model is at the bottom tier of the value hierarchy (value measures)
- Build functions for each value measure to convert a candidate solution's score on the measure to a standard unit called "value"

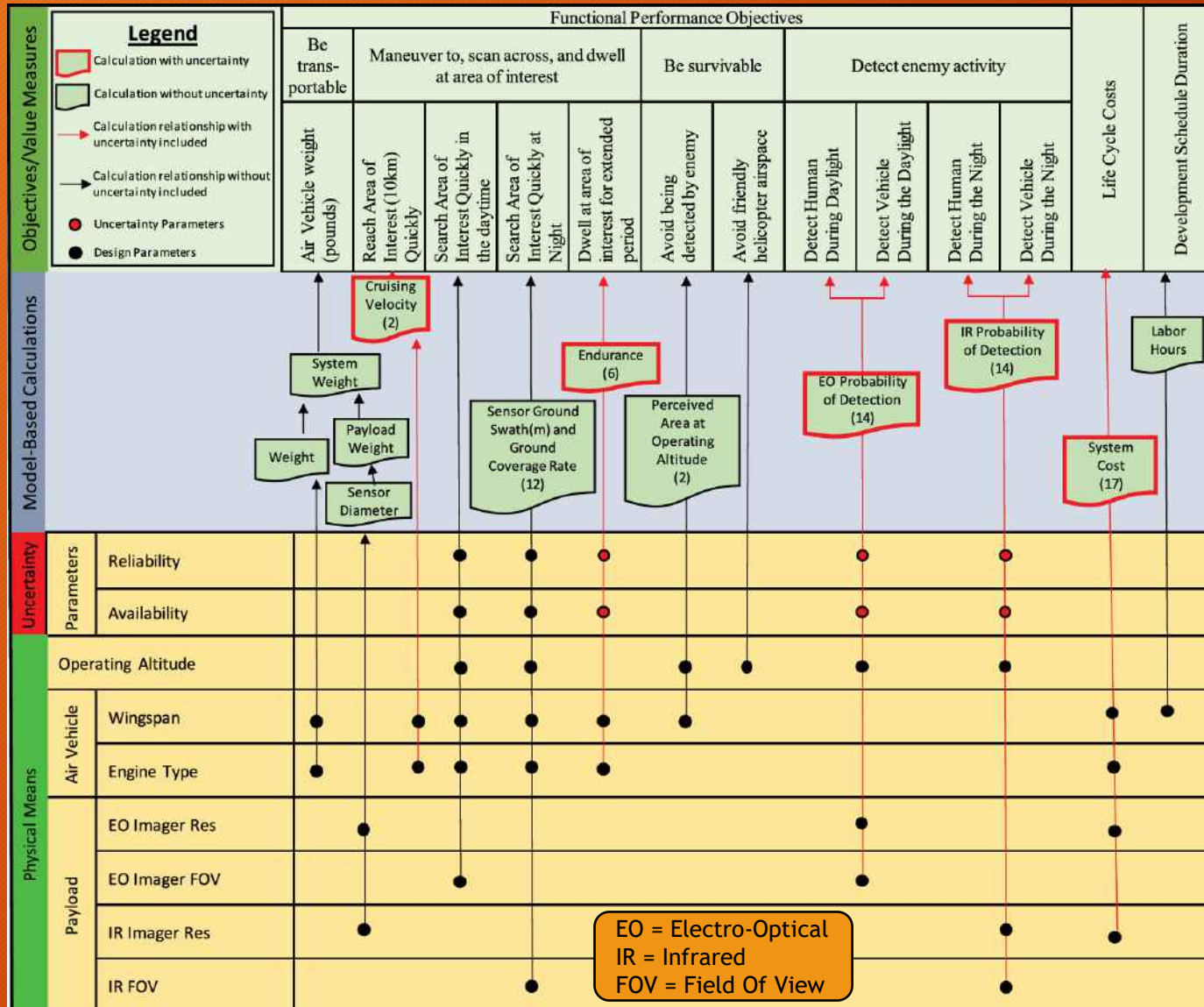


- Also, weight the value measures to reflect their importance to the overall problem and the impact of the variability in their measurement scales on the decision

Multiple-Objective Decision Analysis Overview

- *Multiple-Objective Decision Analysis* (MODA) provides a quantitative method for trading off conflicting objectives
- Often, complex architecture development involves trading off more objectives than can be handled with simple relationships in our heads
- MODA has many different mathematical relationships to help accomplish this
- The most common method is called the *Additive Value Model* to calculate how well candidate solutions satisfy stakeholder values for the problem
- By performing an additive value model analysis for each architecture configuration being evaluated, a total score for each configuration alternative is developed which helps identify the winning solution
- When comparing various alternative configurations, we often perform trade-offs, trading one configuration attribute or capability for another
 - The objective is to find the best trade-off arrangement among all the attributes or capabilities to identify the best configuration alternative
 - The value measures identified in bottom of the value hierarchy serve to help identify all the possible configuration alternatives to be evaluated

Example MODA Study Plan



Value Hierarchy

Model-Based Analysis used to assess viability of possible alternative configurations

System attributes or capabilities traded off to establish complete set of alternative configurations to be evaluated

What is a Tradeoff?

- A *tradeoff* is a reciprocal situational decision that involves giving something up (losing something) in return for gaining something else
- Value judgments are required to make value tradeoffs
 - This infers the need to judge the value of what is given up versus the value of what is gained
- Most important decisions involve multiple objectives
- With multiple-objective decisions, you usually can't have it all
 - You will have to accept less achievement in terms of some objectives in order to achieve more on other objectives
 - But how much less would you accept to achieve how much more?
 - The answers specify a value tradeoff and indicate two consequences that are indifferent to each other (thus, the “tradeoff”)
 - Making the judgments about how much you would give up on one objective to achieve specific amounts on other objectives is the essence of value tradeoffs

Performing Trade-Offs in Architecture

- **Conceptual Architecture**

- Purpose is to downselect multiple possible concepts down to one or a few low-risk choices that meet mission objectives
- Often, the possible concepts are evaluated under a number of scenarios in order to stress the ability of the concepts to meet possible future changes
- Modeling and Simulation (M&S) to evaluate the ability of concepts to meet mission objectives and **Value-Focused Thinking (VFT) Multiple-Objective Decision Analysis (MODA)** to make final concept selection is the best approach to use

- **Logical Architecture**

- Purpose is to trade-off possible functionality and allocation-to-structure alternatives to choose the logical architecture that best satisfies functional/behavioral requirements
- Subject Matter Expert (SME) functional analysis to evaluate functional performance and **Value-Focused Thinking (VFT) Multiple-Objective Decision Analysis (MODA)** to make final functional and component arrangement selections is the best approach to use

- **Physical Architecture**

- Purpose is to trade-off possible physical architecture performance alternatives to choose the architecture that best satisfies performance requirements
- Parametric analysis using the **SysML Parametric Diagram with a Third-Party Parametric Analysis tool** is the best approach to use

Tradeoff Example

- Your team is architecting an ATM system that utilizes a cash dispenser subsystem
- You issue Requests For Information (RFIs) to prospective manufacturers and evaluate the offers in terms of cost and reliability of the cash dispenser subsystems
 - Cost is measured in terms of dollars per dispenser
 - Reliability is measured by the failure rate of dispensers that malfunction in the first 90 days of use
- Objectives
 - Keep cost down
 - Measured in terms of \$ per unit
 - Keep reliability up (keep failure rate down)
 - Measured in terms of % of systems that fail
- You receive two offers:
 - Company A charges \$2000 for a dispenser with an expected failure rate of 8%
 - Company B charges \$2300 for a dispenser with an expected failure rate of 4%

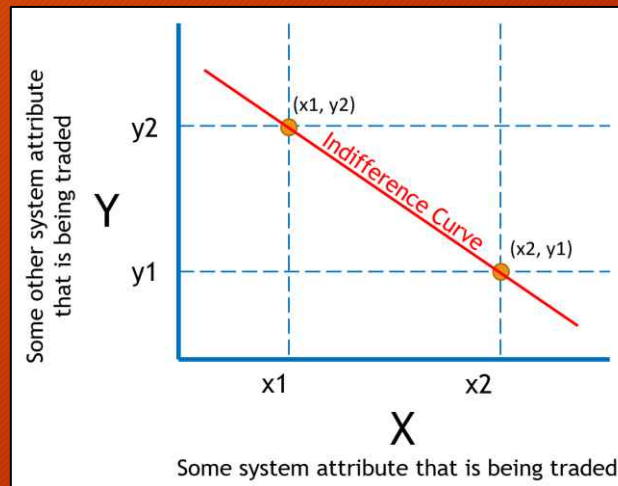
- Different ways of measuring the value
- Or, different “Value Measures”

- \$ per unit is a direct measure of cost
- % of systems that fail is a proxy measure of reliability
 - This proxy measure is needed because we cannot directly measure reliability



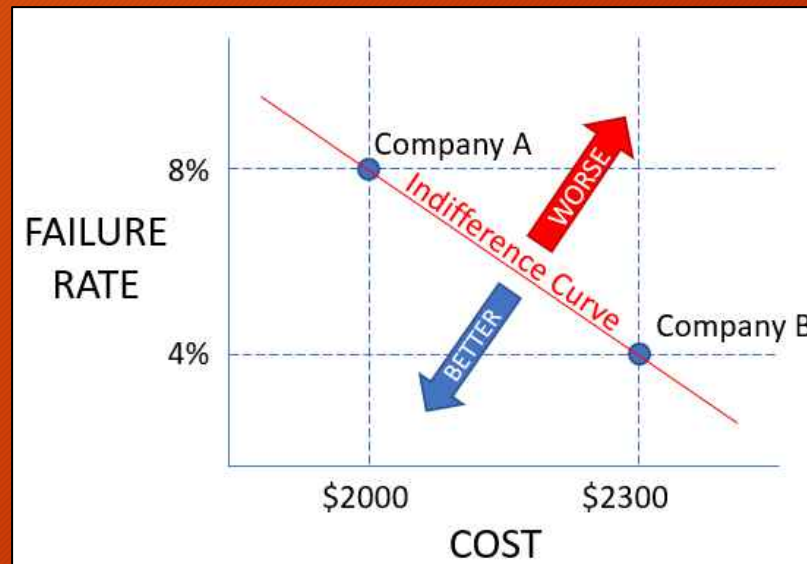
Tradeoff Example (continued)

- To specify a value trade-off, identify two consequences that are indifferent to each other (to you, the two alternatives seem equal)
- For instance, suppose it is determined that (x_1, y_2) is indifferent to (x_2, y_1)
- This indifference pair specifies a value tradeoff that has four equivalent interpretations:
 - From x_1, y_2 , an increase in X to x_2 is compensated for in terms of value by a decrease in Y to y_1
 - From x_2, y_1 , an increase in Y to y_2 is compensated for in terms of value by a decrease in X to x_1
 - From x_1, y_1 , an increase in X to x_2 and an increase in Y to y_2 are equally valued
 - From x_2, y_2 , a decrease in X to x_1 and a decrease in Y to y_1 are equally valued
- The two consequences (x_1, y_2) and (x_2, y_1) lie on an *Indifference Curve*, which is a curve describing a complete set of consequences that are each indifferent to each other



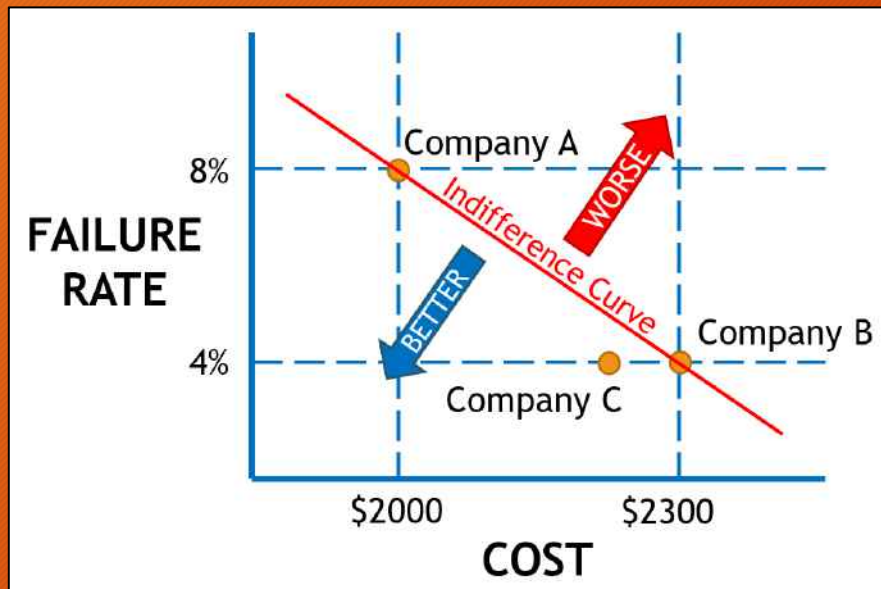
Tradeoff Example (continued)

- Which of these two alternatives is preferred? Choices:
 - IF you **prefer** a decrease in cost from \$2300 to \$2000 over a decrease in failure rate from 8% to 4% - Choose Company A (This is a clear choice)
 - IF you **prefer** a decrease in failure rate from 8% to 4% over a decrease in cost from \$2300 to \$2000 - Choose Company B (This is a clear choice)
 - IF you are **indifferent** to a decrease in cost from \$2300 to \$2000 compared to a decrease in failure rate from 8% to 4% - Equal trade - Choose either Company A or Company B (This is a Tradeoff)
- Let's say that for these two bids, you are indifferent...
- What happens if a third company offers a different bid?



Tradeoff Example (continued)

- Now, suppose you receive a third bid from Company C with a cost of \$2250 and 4% failure rate
- Is this a worse or better choice? Why?
- Because you have already identified what is of equal value to you in terms of cost versus reliability



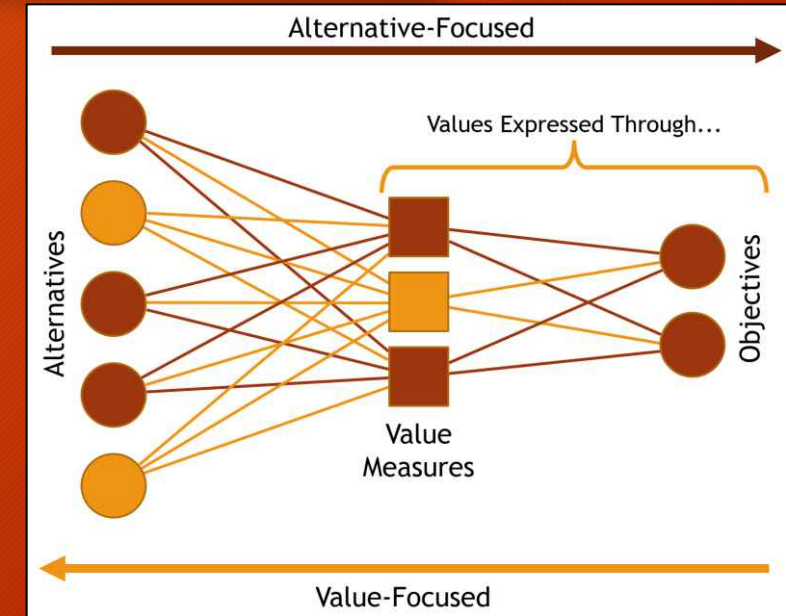
- Making good decisions requires good value tradeoffs
- A good value tradeoff is one that accurately represents your views
- Making decisions consistent with good value tradeoffs will lead you to choose alternatives that are more desirable than other alternatives you could have chosen
- Like any value judgments you make, you must be the final judge about whether the tradeoffs are appropriate for your needs

The Indifference Curve is also called a Value Function

Value-Focused Thinking

- Two main philosophies dominate system decision process strategies
 - *Alternative-Focused Thinking (AFT)*
 - Alternatives are identified first
 - Values are used to choose from a potentially incomplete set of alternatives
 - Entire analysis is biased by the alternatives initially chosen
 - *Value-Focused Thinking (VFT)*
 - A clear understanding of the decision-maker's values drives the creation of alternatives
 - Allows alternatives to be generated that are tailored for the decision context
- **Values** are principles used for the evaluation of consequences of proposed alternatives

The correct systems decision process to use is the VFT approach



Alternative-Focused	Value-Focused
1. Recognize a decision problem	1. Recognize a decision problem
2. Identify alternatives	2. Specify values
3. Specify values	3. Create alternatives
4. Evaluate alternatives	4. Evaluate alternatives
5. Select an alternative	5. Select an alternative

AFT vs VFT Examples

- Buying a car is a typical example of alternative-focused thinking
 - Most people first consider what are their vehicle options and first eliminate any obvious incompatible options
 - They generally do not start with assessing their objectives and measures and then seeing which vehicles fall out of that analysis
 - This is because most of us already “know” what we want
- This is typically not the case in architecture work
 - We can find ourselves with multiple objectives which, when matrixed, can result in many, many alternatives
 - Most of these alternatives are not “off-the-shelf” - they have to be engineered (specified, designed, and built)
 - So we can’t “know” what we want in advance
 - The benefit of matrixing alternatives is that several may pop up that are something we might not have considered otherwise
 - Not considering all possible alternatives at the outset risks not having the potential winning alternative in our sights

Example Design Choices for UAV Study

Design choice	Options
Engine	Discrete choice: Electric Piston
Wingspan	Continuous choice: 2–12 ft.
Operating altitude	Continuous choice: 300–1000 m
Electro-optical (EO) sensor resolution	Discrete choice: 200 × 200, 400 × 400, ..., 1800 × 1800 pixels
EO sensor field of view	Discrete Choice: 15, 30, 45, ..., 90 degrees
Infrared (IR) sensor resolution	Discrete choice: 200 × 200, 400 × 400, ..., 1800 × 1800 pixels
IR sensor field of view	Discrete choice: 15, 30, 45, ..., 90 degrees

In this particular study...

- 145,800 possible design configurations
- 100,000 configurations generated
- 97,424 determined to be infeasible
 - Example: Exceeds weight limit
- 2,576 configurations evaluated

Demonstrating set-based design techniques: an unmanned aerial vehicle case study
(2019) by Small, Parnell, Pohl, Goerger, Cilli, Specking

Additive Value Model

- The Additive Value Model quantitatively assesses the trade-offs between objectives by evaluating the alternative's contribution to the value measures (a score converted to value by single-dimensional value functions) and the relative importance of each value measure (weight)
- As the complexity of the system increases, systems engineers must deal with more stakeholders, define more interfaces, consider more constraints, and identify more requirements
- As a result, the number of conflicting objectives that systems engineers must identify and measure increases
- Systems engineers use multi-objective decision analysis to assess and improve the performance of potential system designs
 - This technique focuses directly on complex decisions, multiple objectives, and uncertainty
 - The *additive value model* is the most commonly used multi-objective decision analysis model

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

This equation is for “n” objectives

- where
 - $v(x)$ is the alternative's value
 - $i = 1$ to n is the number of the value measure (attribute)
 - x_i is the alternative's score on the i_{th} value measure
 - $v_i(x_i)$ is the single dimensional value of a score of x_i
 - w_i is the weight (importance) of the i_{th} value measure
- and $\sum_{i=1}^n w_i = 1$ (all weights sum to one)

In the cash dispenser subsystem example, we have two objectives

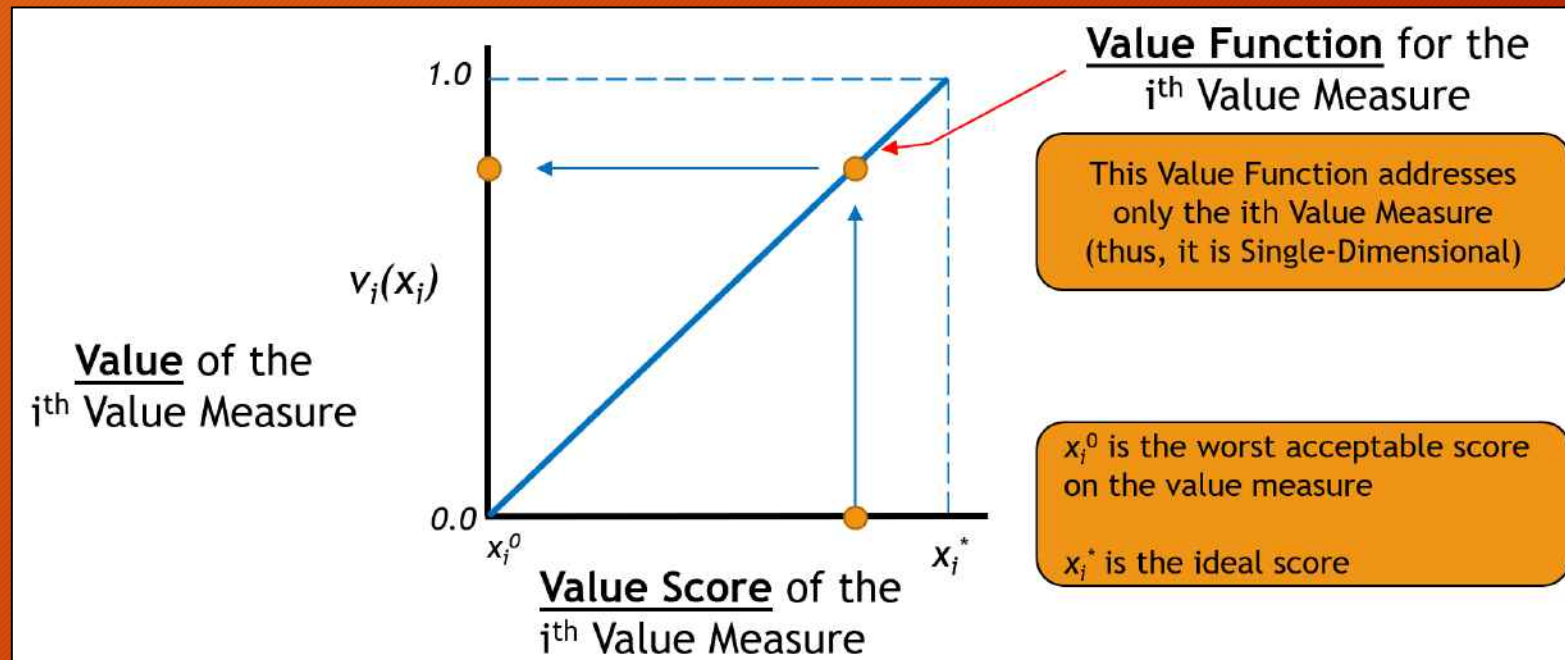
- Reduce cost
- Increase reliability

Therefore, the additive value model for $n=2$ would look like:

$$v(x) = w_1 * v_1(x_1) + w_2 * v_2(x_2)$$

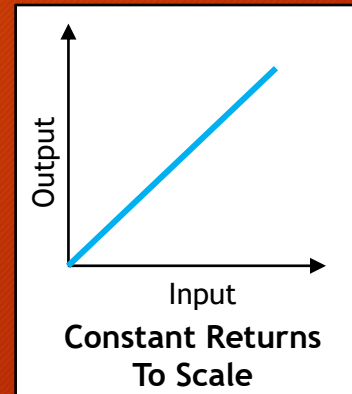
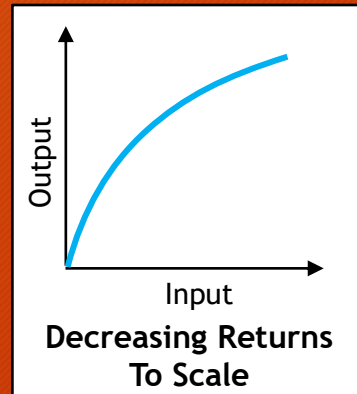
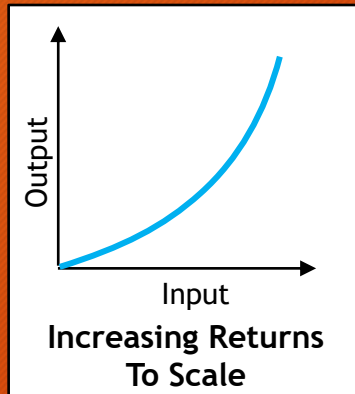
Single-Dimensional Value Functions

- Value functions measure *Returns To Scale* on the value measures
- Value functions are used to convert an inconsistent (from one value measure to another) value measure to a consistent value score
- The value functions can be discrete or continuous and can have any shape
- They are usually monotonically increasing (or decreasing) for value measures aligned with a maximizing (or a minimizing) objective



Returns To Scale

- Each value function, $v_i(x_i)$, measures returns to scale on the range of the value measure and converts a score (x_i) to a value
- In economics, **Economies Of Scale** show the effect of an increased output level on unit costs
- *Returns To Scale* focus only on the relation between input and output quantities
- Returns To Scale describe what happens to long-run returns as the scale of production increases
- It explains the long-run linkage of the rate of increase in output (production) relative to associated increases in the inputs (factors of production)
- There are three possible types of Returns To Scale
- Given a defined manufacturing process, if the inputs are doubled, then
 - If output increases by more than double, then these are *Increasing Returns To Scale* (IRS)
 - If output increases by less than double, then these are *Decreasing Returns To Scale* (DRS)
 - If output is exactly doubled, then these are *Constant Returns To Scale* (CRS)

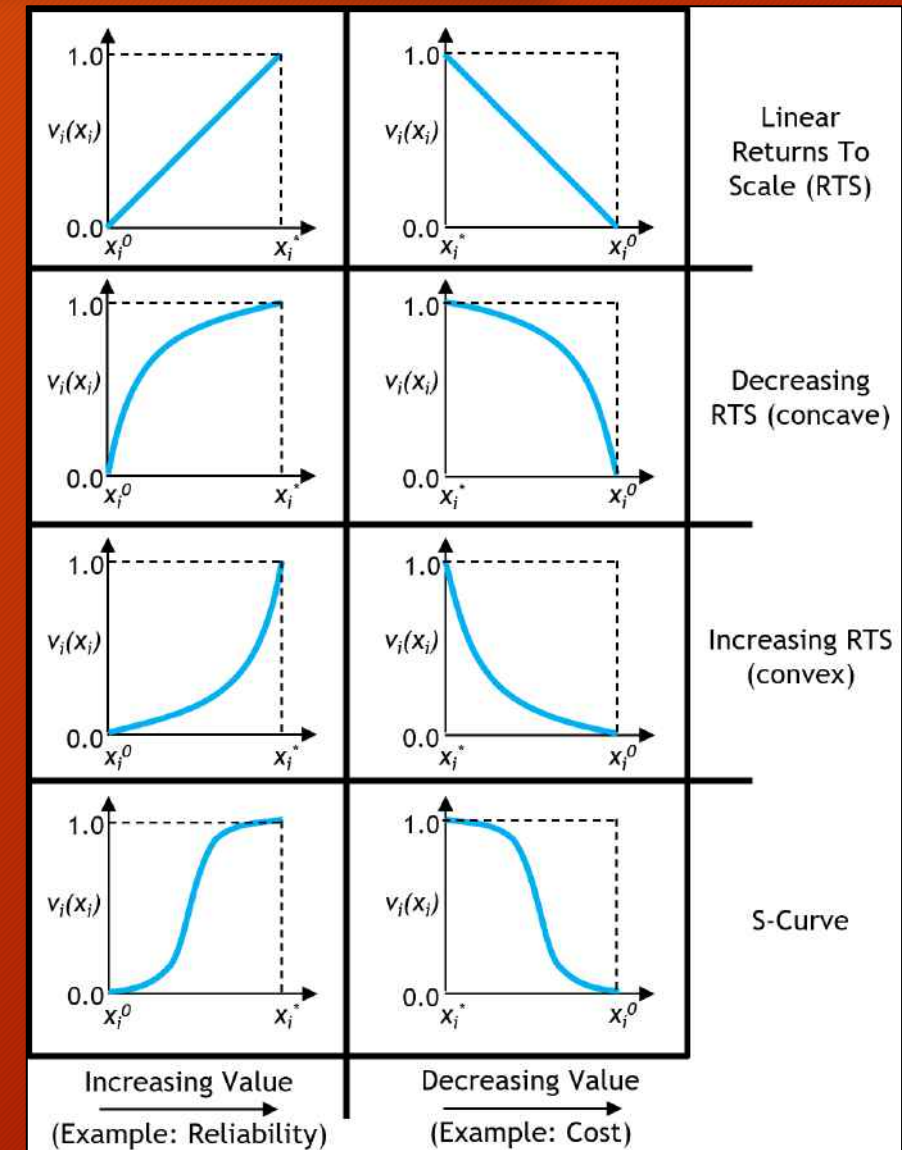


The only reason why Returns To Scale are mentioned here is because Value Functions are based on RTS

Common Single-Dimensional Value Functions

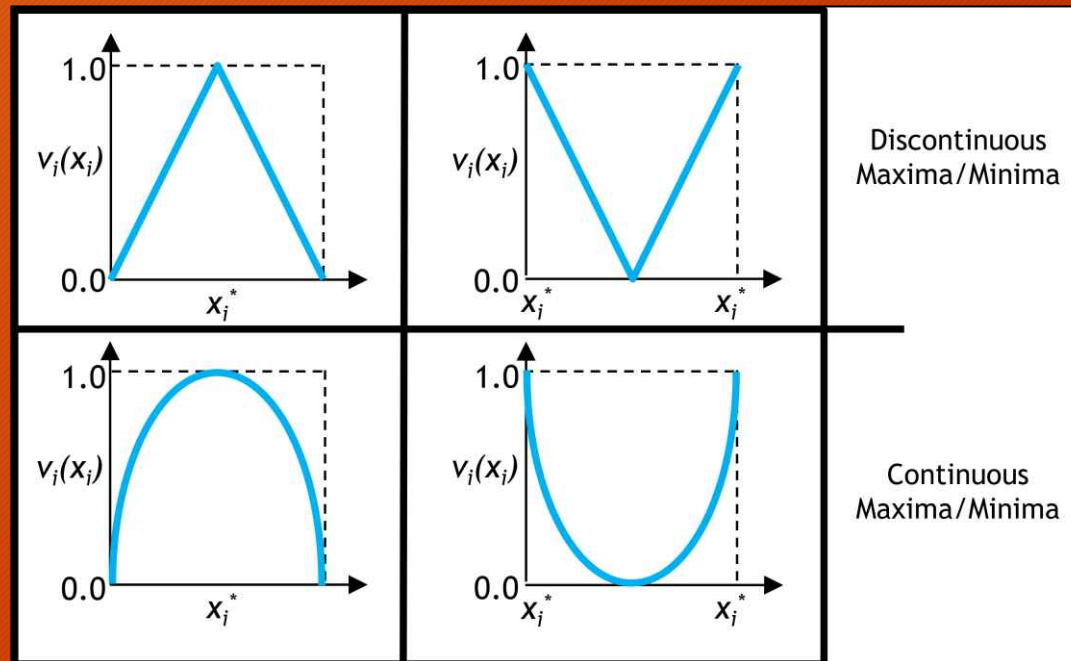
- In practice there are four basic shapes: linear, concave, convex, and an S-curve
- The *linear value function* has Constant RTS: each increment of the measure score is equally valuable
- For increasing value measures, the *concave value function* has Decreasing RTS: each increment is worth less than the preceding increment
- For increasing value measures, the *convex value function* has Increasing RTS: each increment of the measure is worth more than the preceding increment
- For increasing value measures, the *S-curve value function* has increasing, then decreasing, RTS on the measure

The ideal case (x_i^*) always produces the maximum value



Other Value Functions Found in Engineering

- In engineering, some systems can have value functions that display local maxima and minima
- For these kinds of systems, the goal is to arrange the design such that the system (or subsystem, etc) hit the target maxima or avoid the target minima, and thus produce the highest value



Process for Assessing Value

- Carefully define the value measure whose value is being assessed
 - It is critical that the x-axis be carefully defined
 - Identify the minimum acceptable level below which you will not go
- Once the measure is defined, then decide upon the units of value
 - Use a consistent value range among all the value measures
 - Although the units can be any range, the three most common ranges are:
 - 0.0-1.0
 - 0-10
 - 0-100
- Since people make value assessments (people are not precision machines), a reasonable level of precision may be one significant digit
 - Example, 0.5, 5, or 50
 - It is not uncommon to use two significant digits
 - But, beyond two digits you add precision without the requisite accuracy

Process for Assessing Value (continued)

- Assume a curve shape
 - Get the experts to agree on the shape of the single-dimensional value function and the rationale for the returns to scale shown in the curve *before* any points are drawn to fix the curve
 - Record the rationale given by the experts for the shape of the value function
- Then, either
 - Assess the defining parameter(s) such as inflection points
 - Or place points on the graph and fit a curve through the points
- Two value assessment approaches:
 - Absolute Assessment
 - Relative Assessment

Process for Assessing Value (continued)

Two value assessment approaches:

- ***Absolute Assessment***

- Absolute Assessment Technique 1:

- Identify the score on the value measure that provides $Y\%$ of the value
 - Or, identify the percent of the value that yields $Z\%$ of the value measure score on the x-axis
 - Or divide the value measure range into several increments using a technique called bisection

- Absolute Assessment Technique 2:

- Make ratio judgments
 - Example: Increment 1 is Z times as valuable as Increment 2

- ***Relative Assessment***

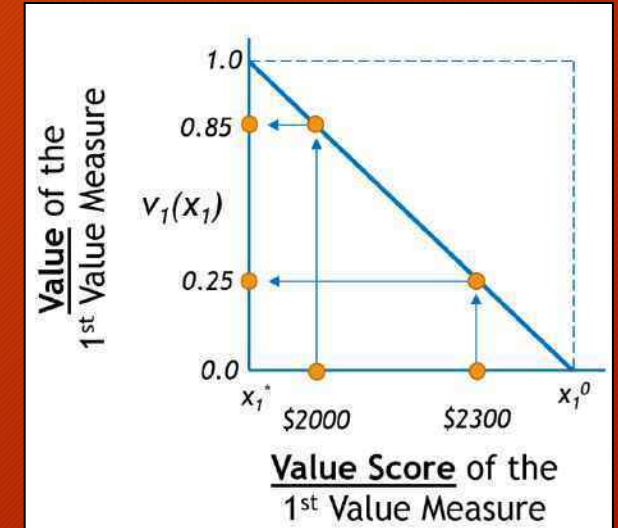
- Relative Assessment Technique:

- Make relative value judgments, for example, Increment 1 has greater value than Increment 2 and Increment 3
 - With enough preference assessments, and knowing that the value increments must sum to the total value, a value curve can be defined

Single-Dimensional Value Function

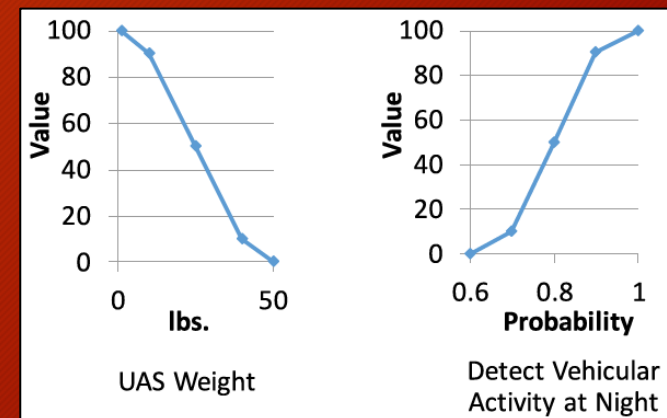
- Developed for each value measure
- The *Value Score* (\$, %, etc) is on the x-axis
- This is converted to a *Value* (ranges from 0 to 1) according to the curve of the *Value Function*
- *Ideal Capability* (x_i^*)
 - Defines the ideal capability that sets an upper bound (for capability) and assigns it the maximum value (1.0, 10, or 100)
 - It is fine to use “stretch goals” as the ideal, but it is not helpful to set it at a point that is clearly far beyond that which is feasible
- In all of the functions, x_i^0 is the worst acceptable score (usually 0) on the value measure and x_i^* is the ideal (usually 1)
- In the example (the first value measure in ATM case)
 - $i = 1$
 - Dollars converted to a unitless value
 - The value for this objective can then be analyzed together with other objectives across different value measures

ATM Cash Dispenser Subsystem Cost



Here, a lower cost value score results in a higher value

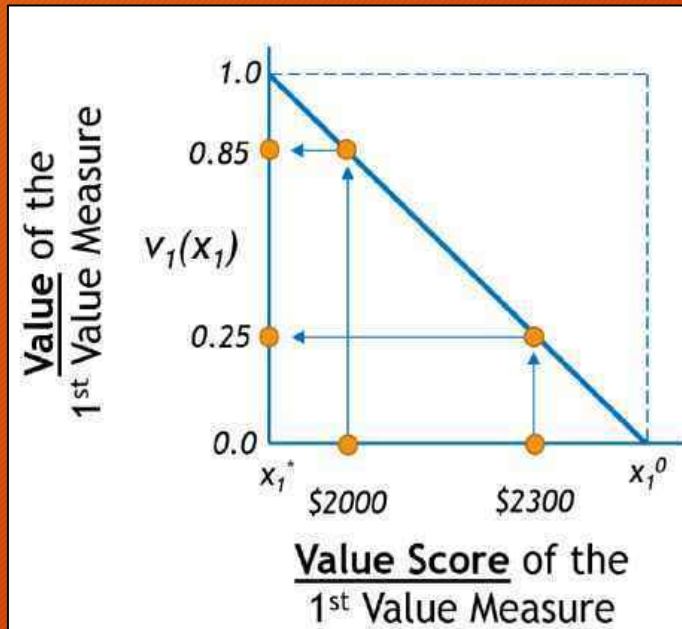
UAV Study Value Function Examples



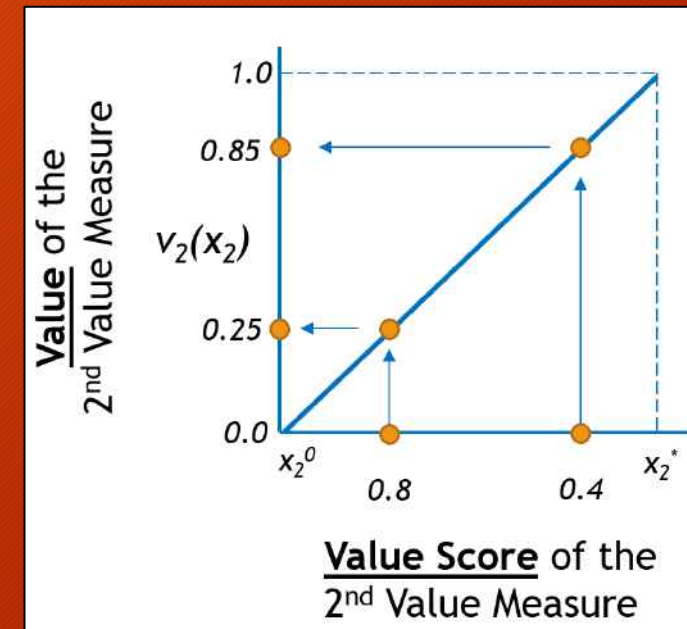
Cash Dispenser Subsystem Example

- Two Objectives (multi-objectives)
 - Reduce Cost
 - Reduce Failure Rate (Improve Reliability)
- Two Value Measures
 - \$ (a direct measure for Cost)
 - % Failure Rate (a proxy measure for Reliability)

COST



RELIABILITY



Cash Dispenser - Two Bids

- Two Value Measures
 - Cost (\$)
 - Failure Rate (%)
- Weights (For now, say they are of equal importance, or 50/50)
 - Cost 50% (0.5)
 - Failure Rate 50% (0.5)

Weights are used to differentiate one value from another by indicating which is more important to us (carries more weight)

Weights must all add up to 1.0

$$v(x) = w_1 v_1(x_1) + w_2 v_2(x_2)$$

Alternative 1:

$$v(x) = 0.5 * 0.85 + 0.5 * 0.25$$

$$v(x) = 0.55$$

Alternative 2:

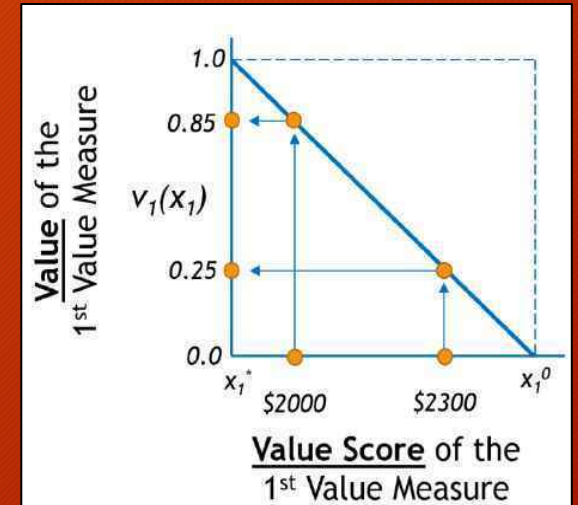
$$v(x) = 0.5 * 0.25 + 0.5 * 0.85$$

$$v(x) = 0.55$$

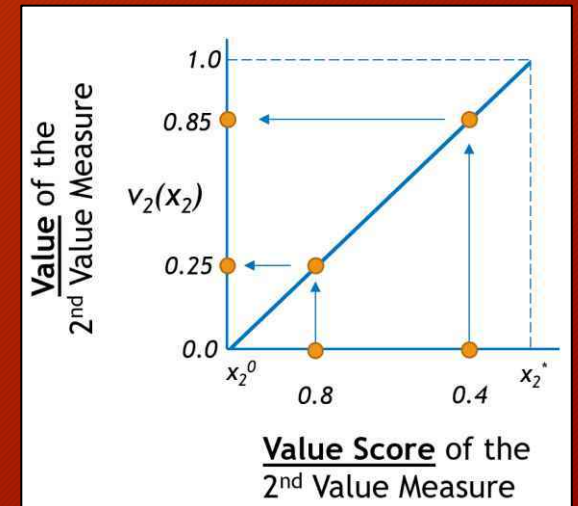
- Alternative 1 (Company A)
 - Cost (\$2000)
 - Reliability (8% Failure Rate)
- Alternative 2 (Company B)
 - Cost (\$2300)
 - Reliability (4% Failure Rate)

- Alternatives are the same because the same weight is applied to each value measure
- This is the indifference case

COST



RELIABILITY



Cash Dispenser - Three Bids

- Two Value Measures
 - Cost (\$)
 - Reliability (% Failure Rate)
- Weights (For now, say they are of equal importance, or 50/50)
 - Cost 50% (0.5)
 - Reliability 50% (0.5)

$$v_i(x_i) = w_1 v_1(x_1) + w_2 v_2(x_2)$$

Alternative 1:

$$v(x) = 0.5 * 0.85 + 0.5 * 0.25$$
$$v(x) = 0.55$$

Alternative 2:

$$v(x) = 0.5 * 0.25 + 0.5 * 0.85$$
$$v(x) = 0.55$$

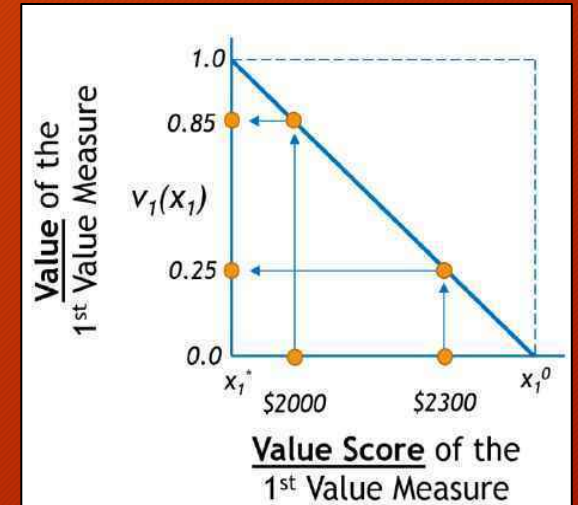
Alternative 3:

$$v(x) = 0.5 * 0.30 + 0.5 * 0.85$$
$$v(x) = \mathbf{0.575}$$

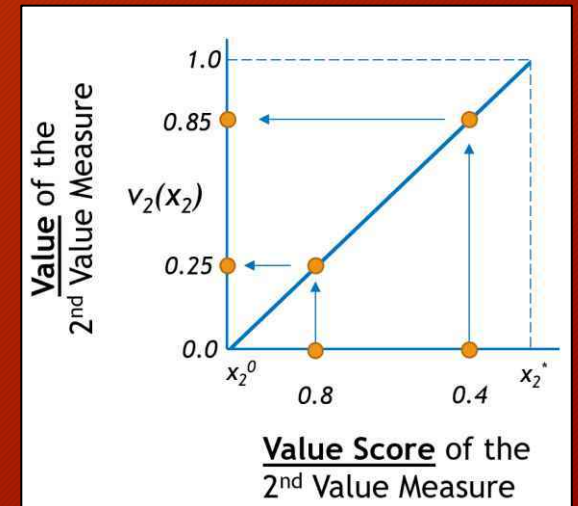
- Alternative 1 (Company A)
 - Cost (\$2000)
 - Reliability (8% Failure Rate)
- Alternative 2 (Company B)
 - Cost (\$2300)
 - Reliability (4% Failure Rate)
- Alternative 3 (Company C)
 - Cost (\$2250)
 - Reliability (4% Failure Rate)

- Alternative 3 is slightly better than the two indifference cases

COST



RELIABILITY



Cash Dispenser - Weights Applied

- Two Value Measures
 - Cost (\$)
 - Reliability (% Failure Rate)
- Weights
 - Cost 60% (0.6) (more important)
 - Reliability 40% (0.4)

$$v_i(x_i) = w_1 v_1(x_1) + w_2 v_2(x_2)$$

Alternative 1:

$$v(x) = 0.6 * 0.85 + 0.4 * 0.25$$

$$v(x) = \mathbf{0.61}$$

Alternative 2:

$$v(x) = 0.6 * 0.25 + 0.4 * 0.85$$

$$v(x) = 0.49$$

Alternative 3:

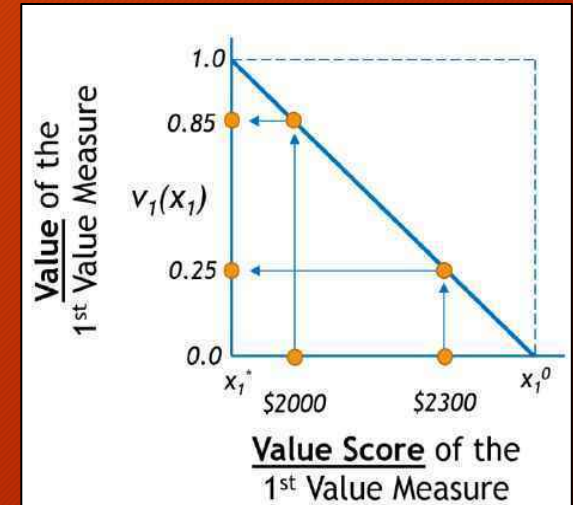
$$v(x) = 0.6 * 0.30 + 0.4 * 0.85$$

$$v(x) = 0.52$$

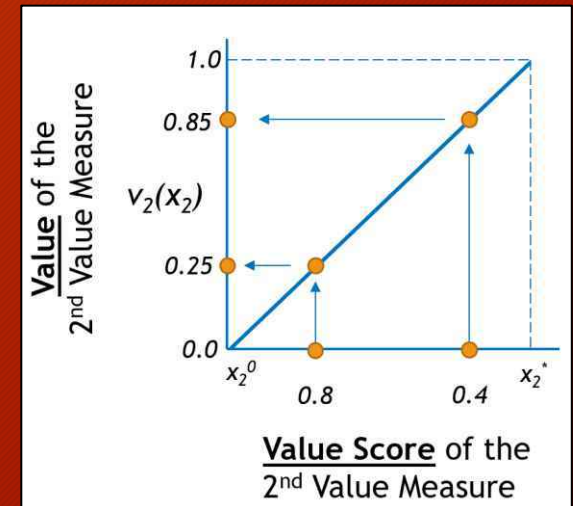
- Alternative 1 (Company A)
 - Cost (\$2000)
 - Reliability (8% Failure Rate)
- Alternative 2 (Company B)
 - Cost (\$2300)
 - Reliability (4% Failure Rate)
- Alternative 3 (Company C)
 - Cost (\$2250)
 - Reliability (4% Failure Rate)

- Alternative 1 is now the better choice because we have placed more weight (more importance) on the value of cost over the value of reliability

COST



RELIABILITY



Use of Weights in Additive Value Model

- The additive value model quantitatively assesses the trade-offs between objectives by evaluating the alternative's contribution to
 - Value measures (a score converted to a value by a single-dimensional value function)
 - Relative importance of each value measure (weight)
- Weights play a key role in the additive value model
- The weights quantify the trade-offs between value measures that assess the achievement of objectives
- The weights among the set of value measures are normalized to sum to 1
- Since values do not depend on the alternative, the additive value model has no index for the alternatives and the same equation is used to evaluate every alternative
- Many individuals, not familiar with the mathematical theory, assess weights using only importance
- However, the weights depend on both importance and variation

Impact of Change in Value Score Range

- Weights depend on both importance and variation
- The *variation* of a measure refers to how large an impact on the decision would changes across its range of value have
 - A measure in which value measure ranges vary widely (differentiates between alternatives more strongly), is weighted more than a measure that does not range as widely



Suppose that originally I was considering vehicles with a safety rating of 1 through 5 STARS



If I later decided to only consider vehicles with 3-5 STARS, then achieving the desired level of safety is more certain, and therefore, the impact of this choice on the overall decision making is less

If I decided to consider only 5 STAR vehicles, safety would no longer be a factor in the decision

Swing Weights vs Importance Weights

- Importance Weights

- Many individuals, not familiar with the mathematical theory, assess weights using only importance of the value measure
- Importance weights are assigned to measures independent of the variation of the measure range
- The question asked is: how important is measure i compared to measure j ?
 - A measure that is very important to the decision should be weighted higher than a measure that is less important
- Unfortunately, this is an inadequately defined question since, in theory, there is no mathematical definition of importance weights

- Swing Weights

- Swing weights play a key role in the additive value model
- They have a sound mathematical foundation derived directly from the additive value model equation
- Swing weights are assigned to value measures not just based on importance, but also the variation of the scales of the value measures
- We assess swing weights by “swinging” the value measure from its minimum acceptable level to its ideal level
- A measure that differentiates between alternatives, that is, a measure in which value measure ranges vary widely, is weighted more than a measure that does not differentiate between alternatives
- If the range of one of the measure scales is reduced, and all other measure ranges are held constant, then the measure's relative swing weight decreases, while the swing weight assigned to the others increases since the weights have to sum to 1.0
- The swing weight matrix is used to properly assess swing weights

Swing Weight Matrix Example

		Importance of the Value Measure to the Decision (Intuitive Judgment)		
		Critical (High)	Important (Medium)	Nice to Have (Low)
Impact of the range of the value measure on the decision (factual judgment)	Large impact	A	B2	C3
	Medium impact	B1	C2	D2
	Small impact	C1	D1	E

- A measure that is very important to the decision and has a large measure range goes in the upper left of the matrix (cell labeled A)
- A value measure that has low importance and has small variation in its scale goes in the lower right of the matrix (cell labeled E)
- A measure that is very important to the decision should be weighted higher than a measure that is less important
- A measure that differentiates well between alternatives (in which value measure ranges vary significantly) is weighted more than a measure that does not differentiate well between alternatives

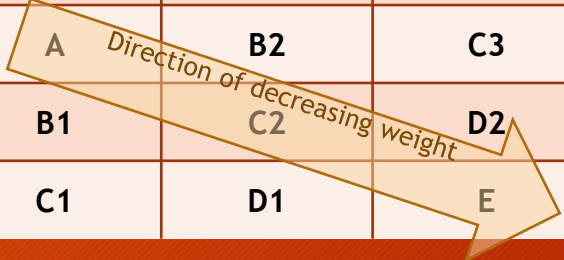
Swing Weight Matrix Example

		Importance of the Value Measure to the Decision (Intuitive Judgment)		
		Critical (High)	Important (Medium)	Nice to Have (Low)
Impact of the range of the value measure on the decision (factual judgment)	Large impact	A	B2	C3
	Medium impact	B1	C2	D2
	Small impact	C1	D1	E

- It is important to ensure consistency of the weights assigned
- It is easy to understand that a very important measure with a high variation in its range (A) should be weighted more than a very important measure with a medium variation in its range (B1)
- It is harder to trade off the weights between a very important measure with a low variation in its range (C1) and an important measure with a high variation in its range (B2)
- Weights should descend in magnitude as we move on the diagonal from the top left to the bottom right of the swing weight matrix
- Multiple measures can be placed in the same cell with the same or different weights

Swing Weight Matrix Example

		Importance of the Value Measure to the Decision (Intuitive Judgment)		
		Critical (High)	Important (Medium)	Nice to Have (Low)
Impact of the Range of the Value Measure on the Decision (Factual Judgment)	Large impact	A	B2	C3
	Medium impact	B1	C2	D2
	Small impact	C1	D1	E



- If we let the letters represent the diagonals in the matrix A, B, C, D, and E; A is the highest weighted cell, B is the next highest weighted diagonal, then C, then D, and then E
- If we denote i to be the label of the cell in the swing weight matrix and f_i to be the unnormalized swing weight of the value measures in each cell, then the following strict inequalities relationships of non-normalized swing weights must hold

Swing Weight Relationship Rules	Inequalities Relationships of Non-normalized Swing Weights
Any measure in cell A must be weighted greater than measures in all other cells	$f_A > f_i$ for all i in all other cells
Any measure in cell B1 must be weighted greater than measures in cells C1, C2, D1, D2, and E	$f_{B1} > f_{C1}, f_{C2}, f_{D1}, f_{D2}, f_E$
Any measure in cell B2 must be weighted greater than measures in cells C2, C3, D1, D2, and E	$f_{B2} > f_{C2}, f_{C3}, f_{D1}, f_{D2}, f_E$
Any measure in cell C1 must be weighted greater than measures in cells D1 and E	$f_{C1} > f_{D1}, f_E$
Any measure in cell C2 must be weighted greater than measures in cells D1, D2, and E	$f_{C2} > f_{D1}, f_{D2}, f_E$
Any measure in cell C3 must be weighted greater than measures in cells D2 and E	$f_{C3} > f_{D2}, f_E$
Any measure in cell D1 must be weighted greater than measures in cell E	$f_{D1} > f_E$
Any measure in cell D2 must be weighted greater than measures in cell E	$f_{D2} > f_E$

Assessing Non-Normalized Swing Weights

- Once all the value measures are placed in the cells of the matrix, we can use any swing weight technique to obtain the non-normalized weights as long as we follow the consistency rules cited above
- In assigning weights, the stakeholders need to assess their tradeoffs between level of importance and level of variation in measure scale
- One approach would be to assign the measure in cell A (the upper left-hand corner cell) an arbitrary large non-normalized swing weight, for example, 100 ($f_A = 100$)
- Using the value increment approach, we could assess the weight of the lowest weighted measure in cell E (the lower right-hand corner) the appropriate swing weight, for example, 1
 - This means the swing weight of measure A is 100 times more than that of measure E
- It is important to consider what the maximum in cell A should be
 - Common choices are 1000 and 100
 - Of course f_E can be other numbers besides 1
 - If we use 100 and 1, we have three orders of magnitude
 - If we use 1000 and 1 we have four orders of magnitude
- Using a value increment approach, non-normalized swing weights can be assigned to all the other value measures relative to f_A by descending through the very important measures, then through the important measures, then through the less important measures

Example Swing Weight Matrix

Non-normalized swing weights applied to each cell of the matrix

Variation of scale		Ability to change									
		Level of Importance: High		Level of Importance: Medium		Level of Importance: Low					
		Mission immutable (Very difficult to change)		Mission support (Difficult to change without external support)		Mission enablers (Change with Army dollars)					
		Large		Moderate		Small					
		Small		Moderate		Large					
Hvy maneuver area Direct fire Brigade capacity 100		Light maneuver area Indirect fire 90		Inter-service partnering Area cost factor 75		Housing avail. Crime index Maintenance / manuf. 50		RDTE diversity 20		Supply & storage Operation/administrative Ammo storage 10	
Force deploy Materiel deploy Airspace 90		Critical infrastructure Test ranges Mobilization history 75		Munitions production Urban sprawl Accessibility 50		Work force availability 20		Military Operations Urban Terrain 10		Applied instruction General instruction 5	
Buildable acres 75		Soil resiliency Joint facilities 50		Employment opportunity Water quantity Installation unit cost Environmental elasticity Connectivity 20		Medical availability Noise contours Air quality In-state tuition 10		C2 target facilities 5		1	

2005 US Army Base Realignment and Closure (BRAC) study performed by Parnell, Ewing, and Tarantino

Some cells populated with multiple value measures

Calculating Normalized Swing Weights

- We can normalize the weights for the measures to sum to 1 as follows:

$$w_i = \frac{f_i}{\sum_{j=1}^n f_j}$$

- where
 - f_i is the non-normalized swing weight assessed for the i^{th} value measure
 - $j = 1$ to n for the number of value measures
 - w_i are the normalized swing weights

Example of Normalized Swing Weight Matrix

Swing weights normalized

Variation of scale		Ability to change					
		Level of Importance: High		Level of Importance: Medium		Level of Importance: Low	
		Mission immutable (Very difficult to change)		Mission support (Difficult to change without external support)		Mission enablers (Change with Army dollars)	
Large	Hvy maneuver area Direct fire Brigade capacity 0.13	Light maneuver area Indirect fire 0.12	Inter-service partnering Area cost factor 0.10	Housing avail. Crime index Maintenance / manuf. 0.07	RDTE diversity 0.03	Supply & storage Operation/administrative Ammo storage 0.01	
Moderate	Force deploy Materiel deploy Airspace 0.12	Critical infrastructure Test ranges Mobilization history 0.10	Munitions production Urban sprawl Accessibility 0.07	Work force availability 0.03	Military Operations Urban Terrain 0.01	Applied instruction General instruction 0.00	
Small	Buildable acres 0.10	Soil resiliency Joint facilities 0.07	Employment opportunity Water quantity Installation unit cost Environmental elasticity Connectivity 0.03	Medical availability Noise contours Air quality In-state tuition 0.01	C2 target facilities 0.00	 0.00	

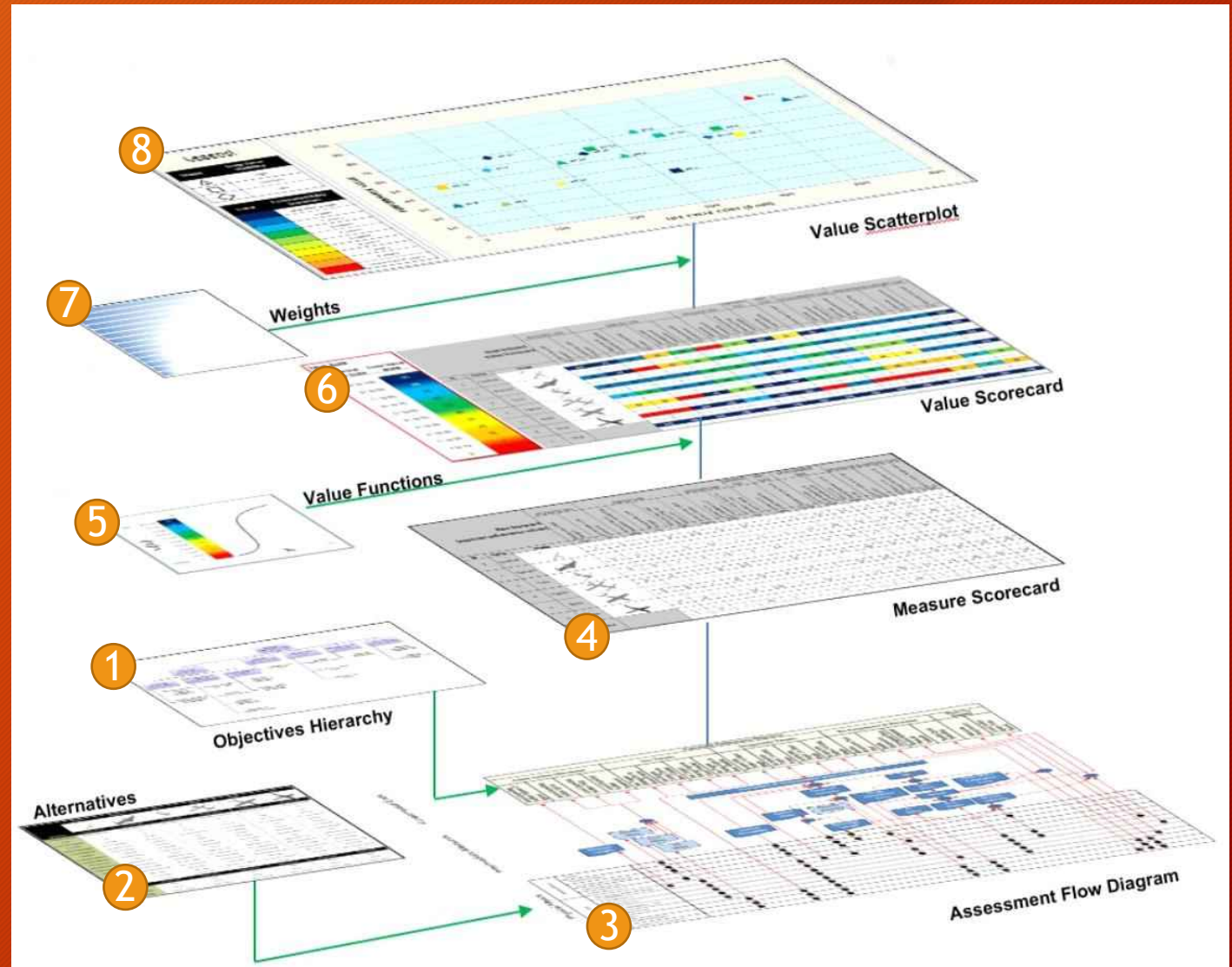
2005 US Army Base Realignment and Closure (BRAC) study performed by Parnell, Ewing, and Tarantino

Some cells populated with multiple value measures

MODA Process Overview Example

From: Improving Defense Acquisition Outcomes Using an Integrated Systems Engineering Decision Management (ISEDMD) Approach

1. Develop Objectives Hierarchy
2. Develop Alternatives
3. Incorporate Objectives Hierarchy and Alternatives into Assessment Flow Diagram
4. Develop Measure Scorecard
5. Develop Value Functions
6. Apply Value Functions to Measure Scorecard to produce Value Scorecard
7. Develop Weights
8. Apply Weights to Value Scorecard to produce Value Scatterplot



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