SYSTEMS ENGINEERING RESEARCH CENTER

Insights on Making Decisions Concerning Architectures

ART-016: IME Architecture Process for Vertical Lift Systems

PI: Dr. Bryan Mesmer

Sponsor: U.S. Army Combat Capabilities Development Command Aviation & Missile Center Technology Development Directorate Integrated Mission Equipment; Contract #: W15QKN-18-D-0040

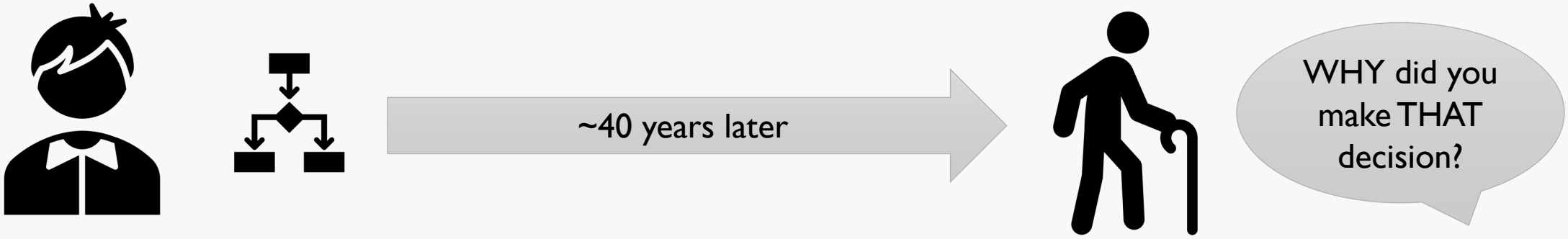
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

ANNUAL RESEARCH REVIEW 2022

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Motivation

- A rigorous, repeatable, systematic approach to architecting is needed to:
  - Provide justification for decisions to present stakeholders
  - Provide justification for decisions to future stakeholders
  - In general, improve architectures



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Research Goal

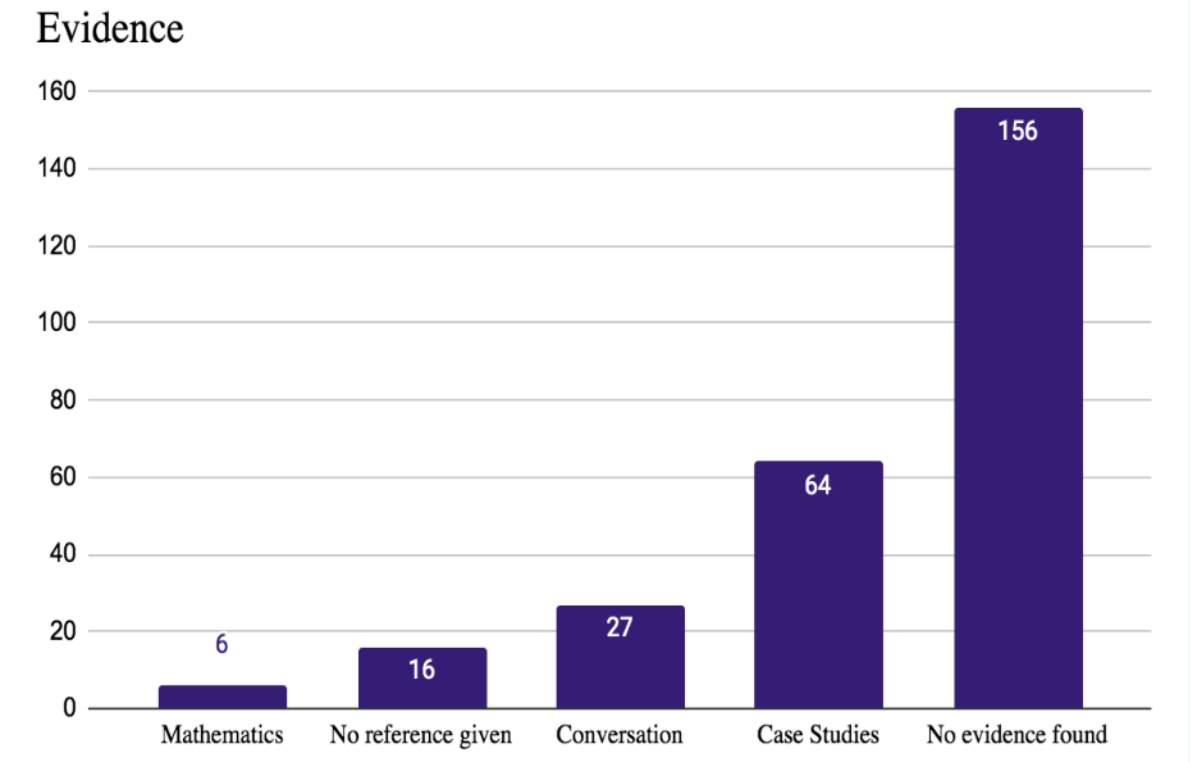
- Goal: Develop a decision making process for architectural decisions

- To accomplish goal, 5 steps each with research questions are investigated
  - Step 1: Decision Framework
  - Step 2: Preferences
  - Step 3: Beliefs
  - Step 4: Alternatives
  - Step 5: Designing vs Architecting

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 1: Establish a Decision Framework

- RQ1: What is the current decision making approach in architecting?
- Significant focus on heuristics-based decision making
- Heuristics that are used lack evidence-based foundation
  - Based on study examining 4 sources and each heuristics' identified references



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 1: Establish a Decision Framework

- RQ2: What decision making approach should architects use?

- Decisions concerning architectures have some challenges:
  - Uncertain outcomes
  - Extended and uncertain timing of outcomes
  - Uncertain future stakeholders (including future implementers)
  - Multiple stakeholders

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 1: Establish a Decision Framework

- RQ2: What decision making approach should architects use?

- Many different options exist:
  - Quality Function Deployment
  - Pugh Method
  - Analytic Hierarchy Process
  - Axiomatic Design
  - Taguchi
  - Six Sigma
  - Etc.

- Common issues are: inaccurate preference measures, non-repeatable, incapable or non-rigorous incorporation of uncertainty

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 1: Establish a Decision Framework

- RQ2: What decision making approach should architects use?

- We want a decision analysis technique that is
  - normative (how people should make decisions)
  - mathematically rigorous

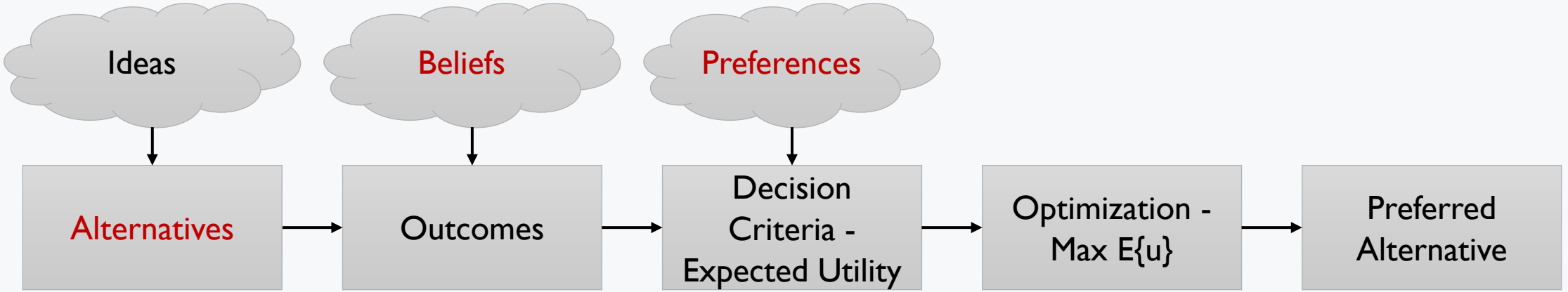
  to enable justifiable and repeatable decisions.
- Leverage knowledge and experiences from engineering community
- Normative Decision Theory
  - Mathematically derived theory that prescribes how people should make decisions in order to be consistent with the available alternatives, their beliefs about the outcomes of the alternatives, and their preferences over the outcomes of the alternatives

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 1: Establish a Decision Framework

- RQ2: What decision making approach should architects use?

- Normative Decision Theory
  - Expected Utility Theory for examining single decision maker
  - Bayesian Game Theory for examining interacting decision makers

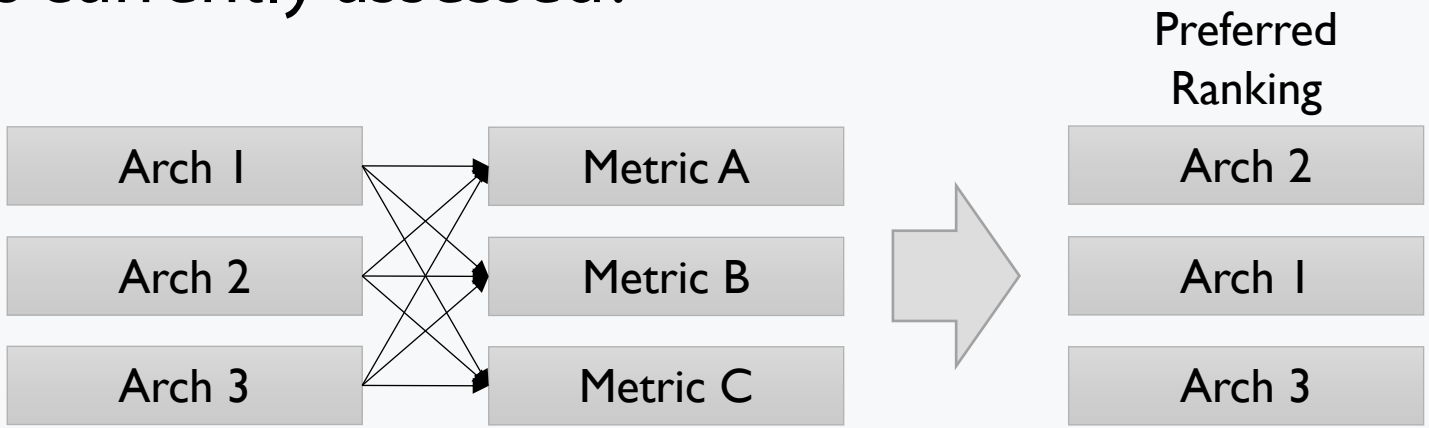


Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

- RQ3: How are architectures currently assessed?

- Lit. Search to determine:
  - Architecture Metrics
  - Architecture Preferences



- Literature search produced no significant findings on assessment methods for architectures
  - If you are aware of existing methods please let us know!
- Stakeholders and implementers are familiar with expressing metrics and preferences on systems, rather than architectures

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

- RQ4: How can architectures currently be assessed?

- Value Model
  - a scoring system[1]
  - takes in all relevant attributes of a system and delivers a measure of preference for the system[2]
  - maps every point in the attribute space to a unique scalar value[2]
  - Measurement in expected utility theory

- What are possible attributes?

1.Collopy, P., Horton, R., "Value Modeling for Technology Evaluation", AIAA Joint Propulsion Conference, Indianapolis, IN, July, 2002 2. Keller, S., Collopy, P., "Value Modeling for a Space Launch System", CSER '13, Atlanta, GA, March, 2013

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

- RQ5: What attributes of architectures are desired by current Army stakeholders?

- Findings from U.S. Army indicate that stakeholders discuss business drivers, such as cost and schedule, and lifecycle quality attributes, such as maintainability and robustness

- SEI is investigating decompositions of quality attributes into measurable quality characteristics

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

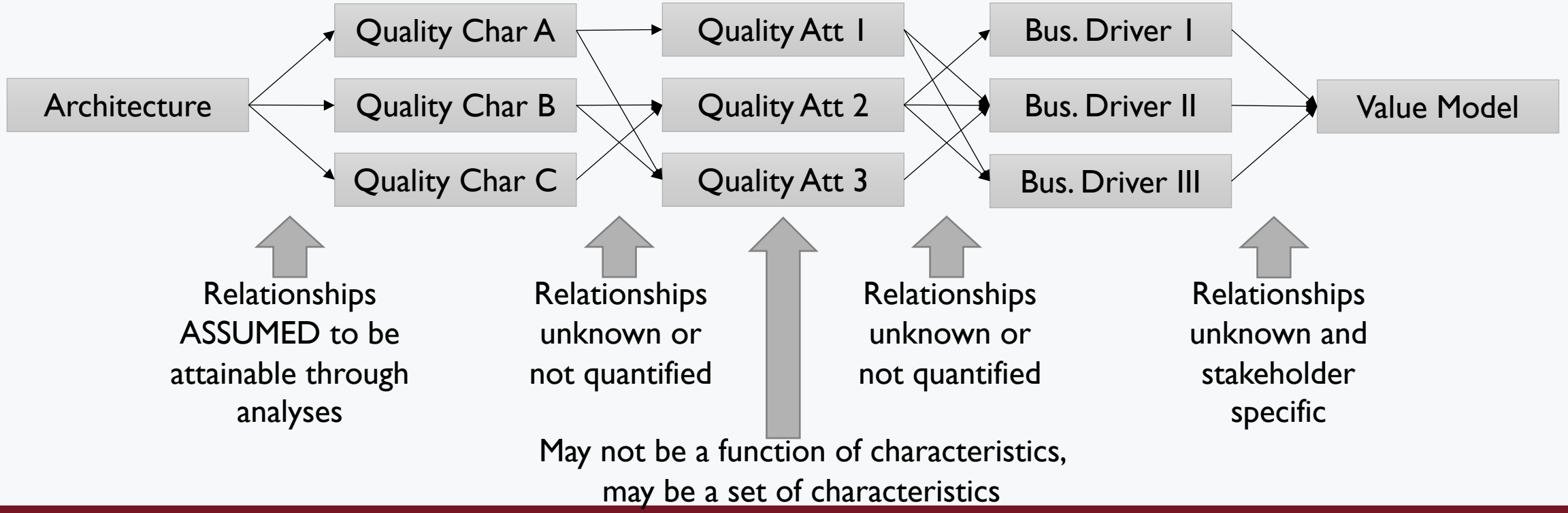
Step 2: Determine Preferences on Architecture Outcomes

- RQ6: How can attributes of architectures be used to form a value model?
- Ideal Case:

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

- RQ6: How can attributes of architectures be used to form a value model?
- However, the key relationships are unknown or not quantified:



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

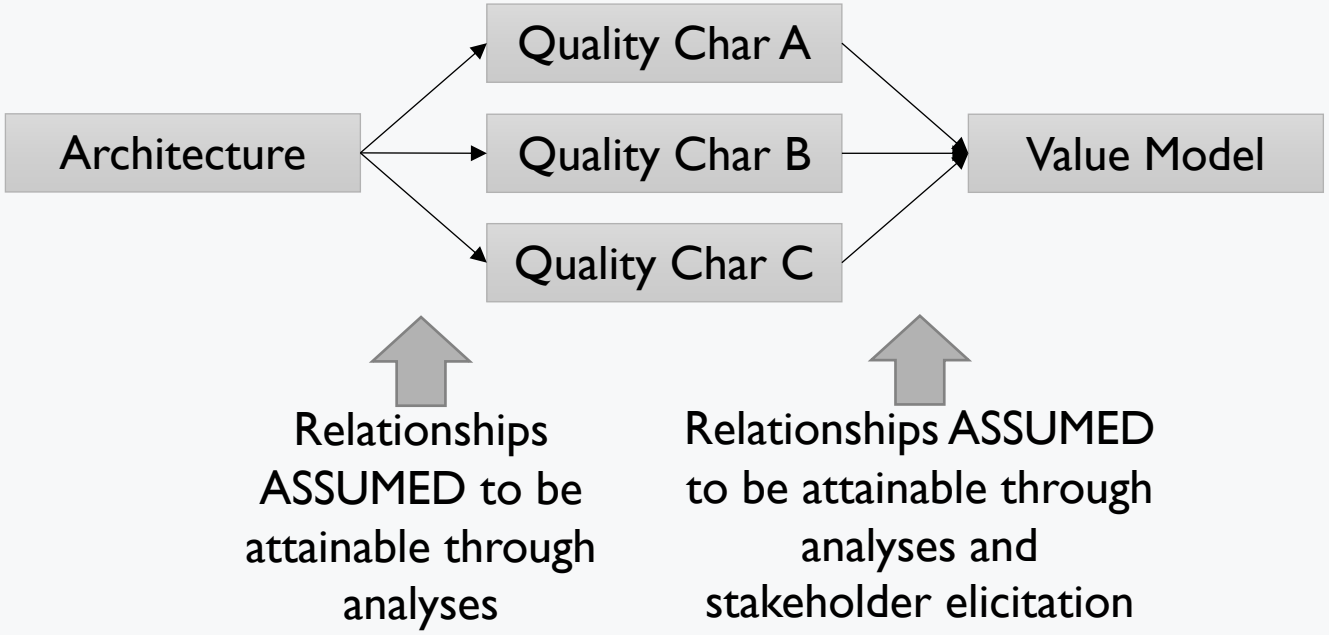
- RQ6: How can attributes of architectures be used to form a value model?

- Because there is unclear understanding of relationships with quality attributes we cannot establish a meaningful mathematical representation of preference (value model) from current work that includes business drivers directly as value model attributes.

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

- RQ6: How can attributes of architectures be used to form a value model? Question still open
- To move forward, will collapse the metric flow to just quality characteristics feeding the value model.



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

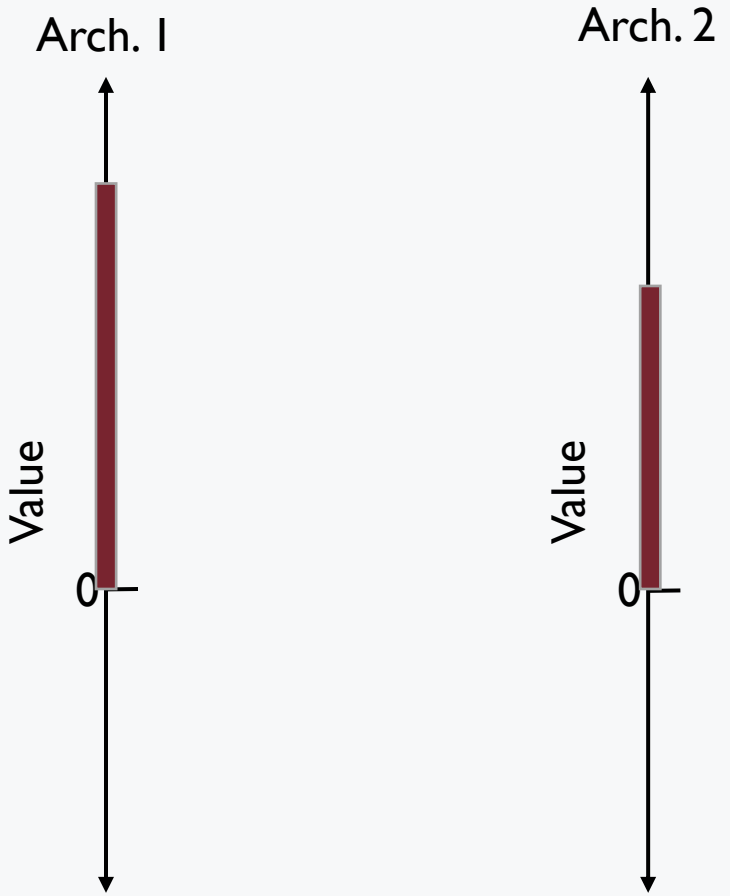
- RQ7: What are potential stakeholder preferences?
- From discussions with Army collaborators
  - Business Driver Focused (Cost, Schedule, and Capability)
  - Quality Attribute Focused (Maintainability, Robustness, Interoperability, etc.)
  - Flexibility of Architecture (Ease of adapting to new stakeholder preferences requires little rework)
  - Effort of Implementation (Resources required to further develop and enact architecture)
  - Many more POTENTIAL preferences
- We will refer to the measure of preference generally as value.

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

- RQ8: How to incorporate preferences over time?

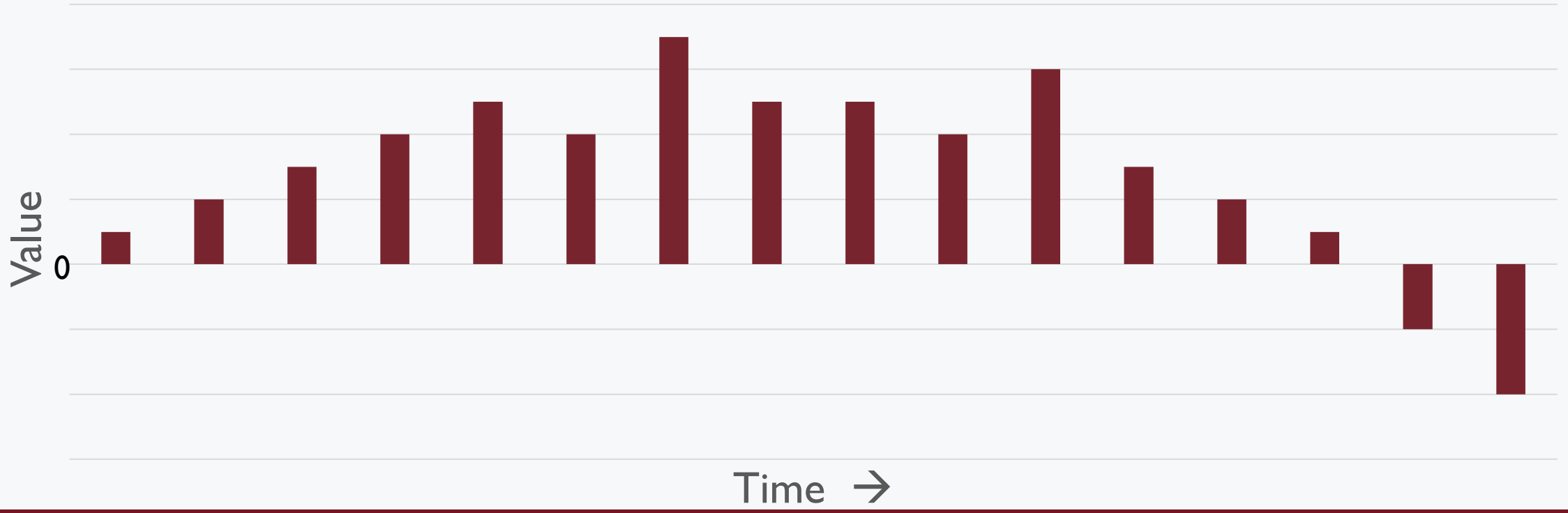
- Architecture 1, with higher value, would be preferred
- But this is only looking at the value at time 0, what about the value over the lifecycle of an architecture?



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

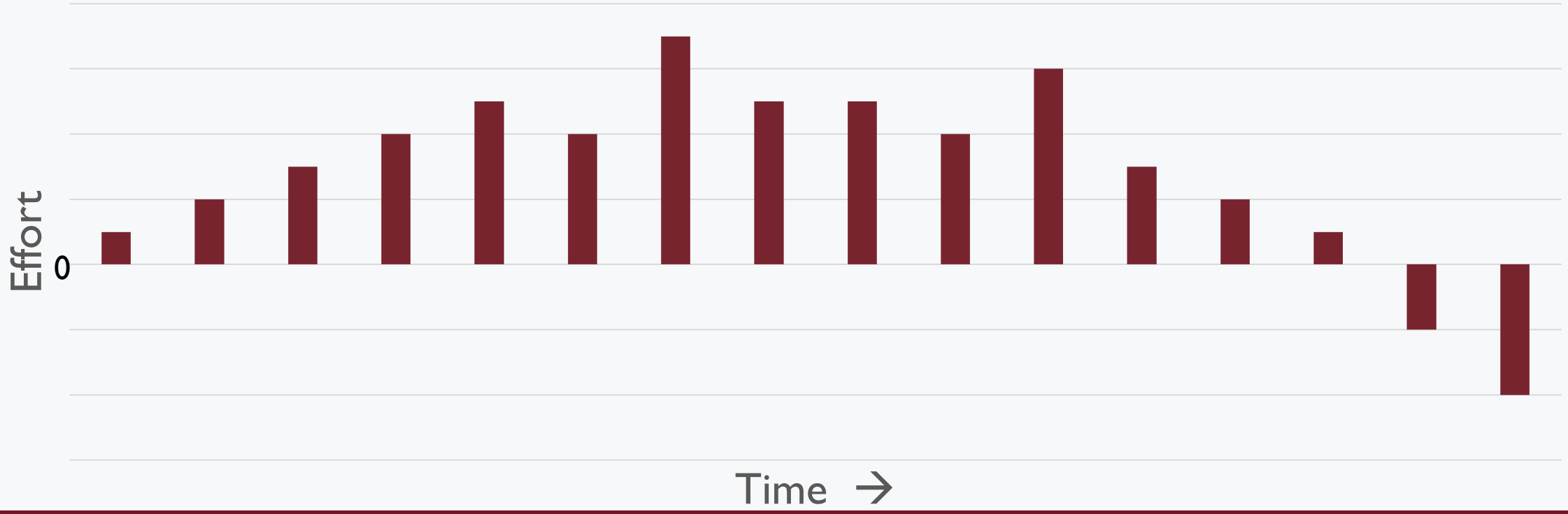
- RQ8: How to incorporate preferences over time?
- Perceived “value generated” by architecture at different times is non-constant



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

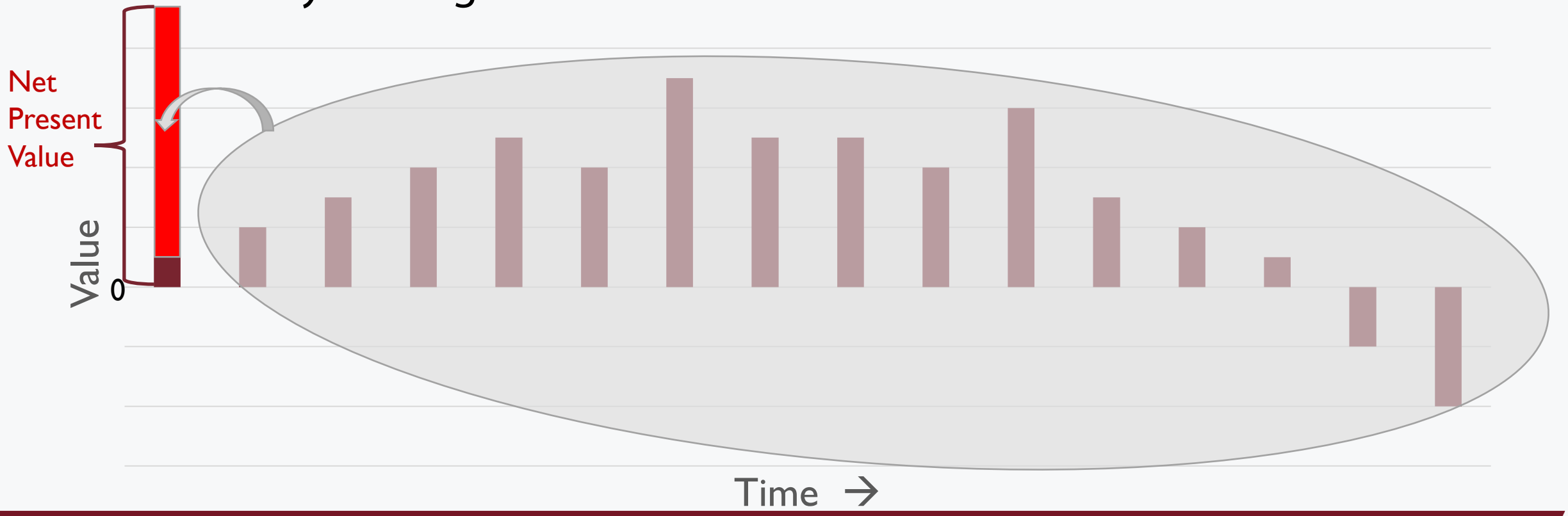
- RQ8: How to incorporate preferences over time?
- Ex: Each time period could be the perceived effort needed to develop or use the architecture at that time period



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

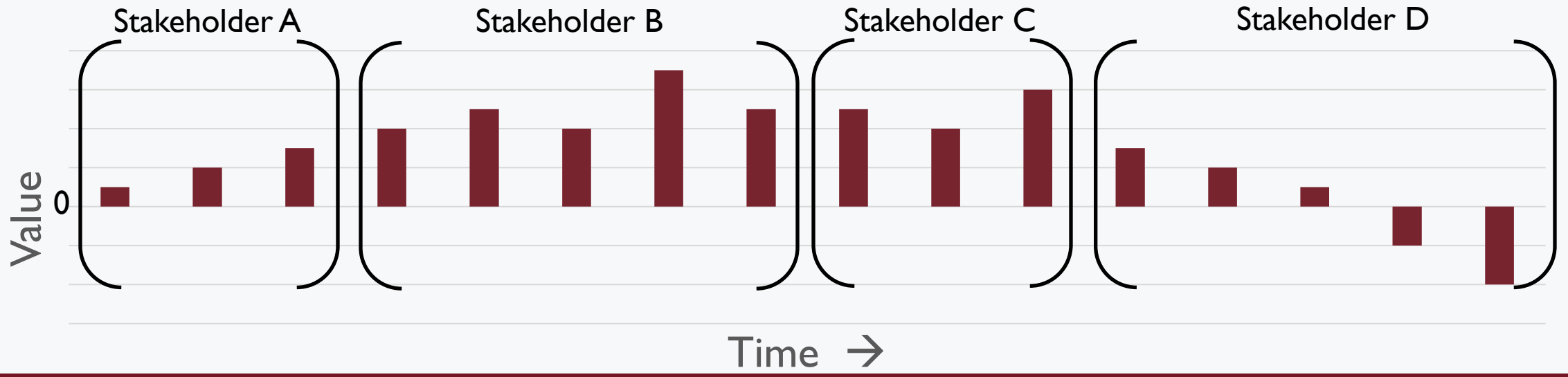
- RQ8: How to incorporate preferences over time?
- Values can be collapsed to present using "time value" of value, where commonly value generated later is discounted



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

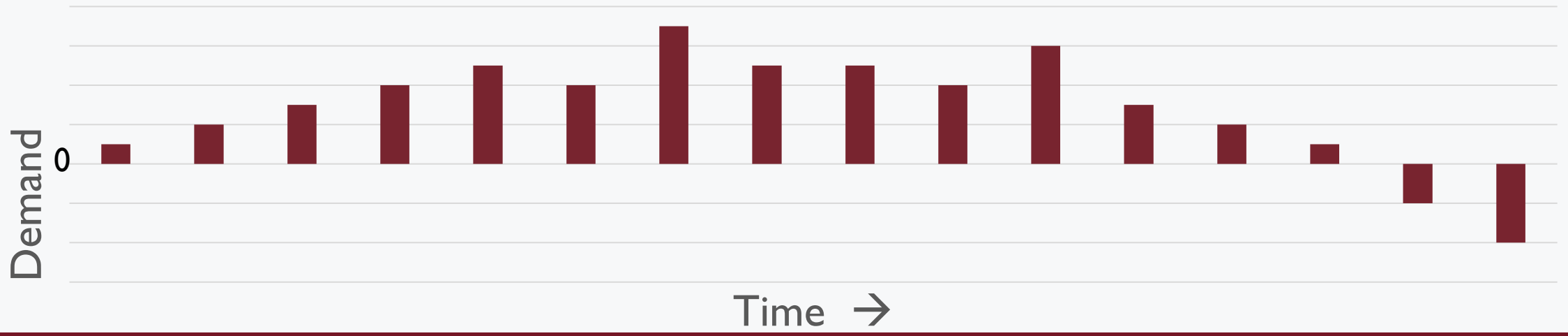
- RQ9: How to incorporate changing stakeholders?
- Different stakeholders will be involved in architecture at different time periods
  - Generals
  - Project Managers
  - System Designers
  - Etc.
- Different stakeholders will have different preferences



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

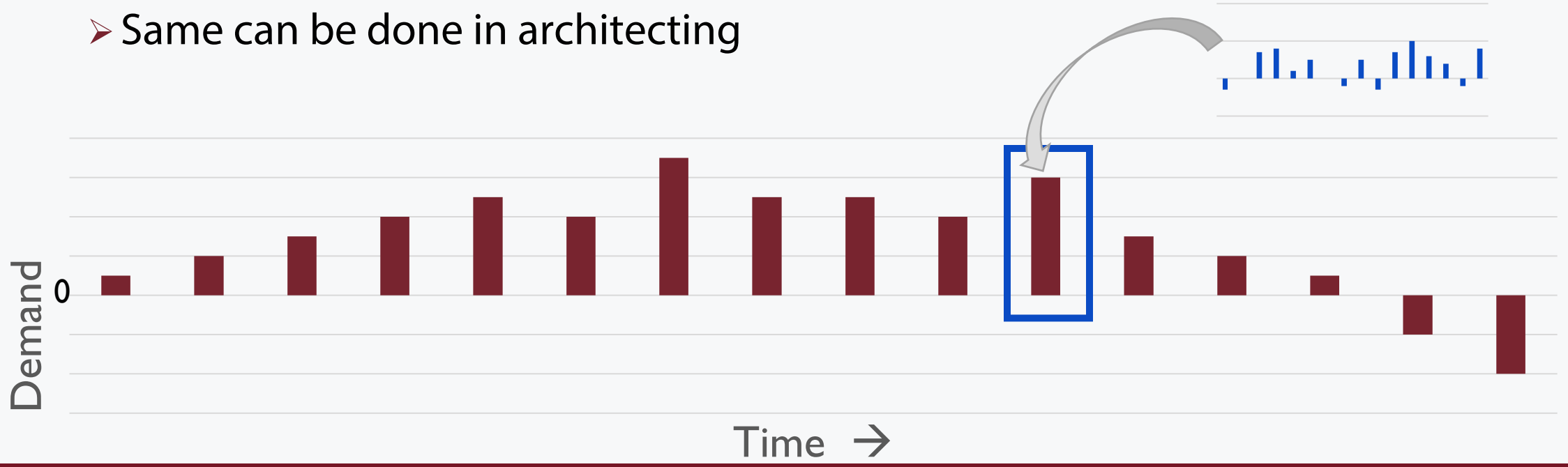
- RQ9: How to incorporate changing stakeholders?
- "Multiple stakeholders" is something we deal with in other areas of engineering decision making regularly
- In product evaluation, it is typical to determine the demand for a product at each time period with different customers



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

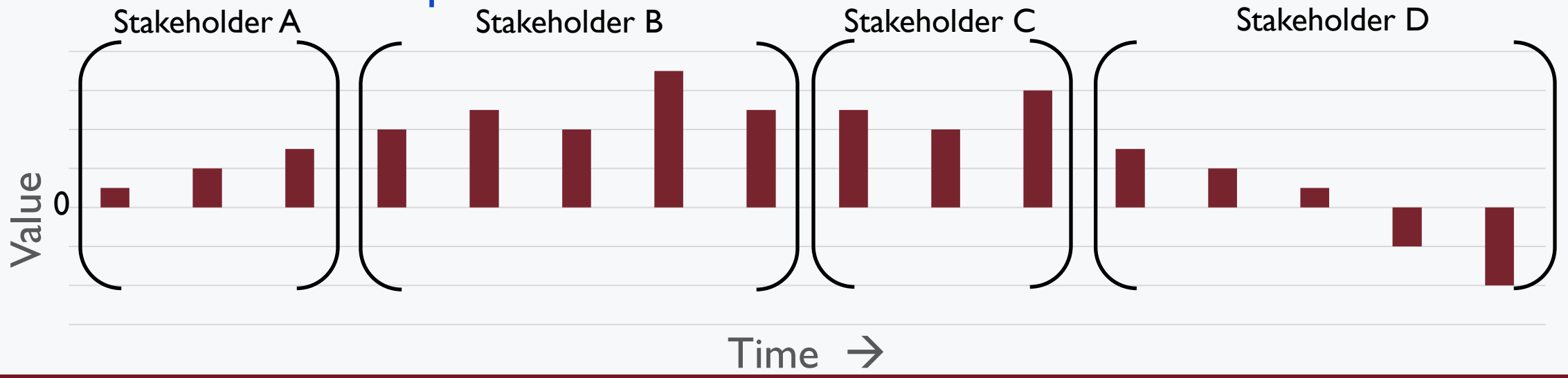
- RQ9: How to incorporate changing stakeholders?
- Lets explore a single time period in a demand model
  - Assume a single customer at a time period
  - That customer will be valuing the product over the customer's expected lifetime of the product, determining a net present value
  - Same can be done in architecting



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

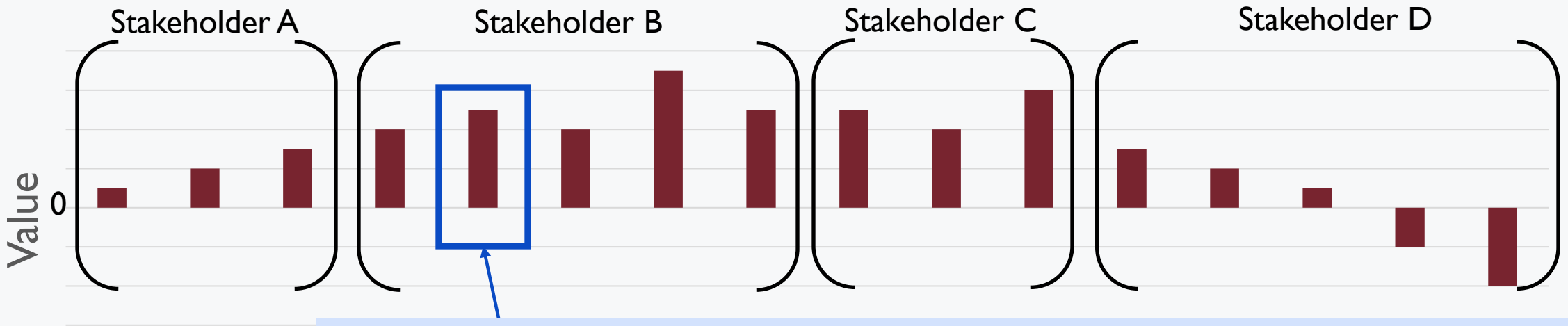
- RQ9: How to incorporate changing stakeholders?
- Perceived "value generated" by architecture at each time period
- Different stakeholders will have different preferences, but all preferences measured in terms of same value units
- The meaning of the value at the time period is dependent on the decision-maker's preference



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

- RQ9: How to incorporate changing stakeholders?
- Example: The preference of the architect is to ensure stakeholder approval of the architecture over its lifespan
  - Potential problem formulation is to maximize the net present value where value at each time period is the stakeholder's net present value (present being that time period) of the architecture from that time period onwards

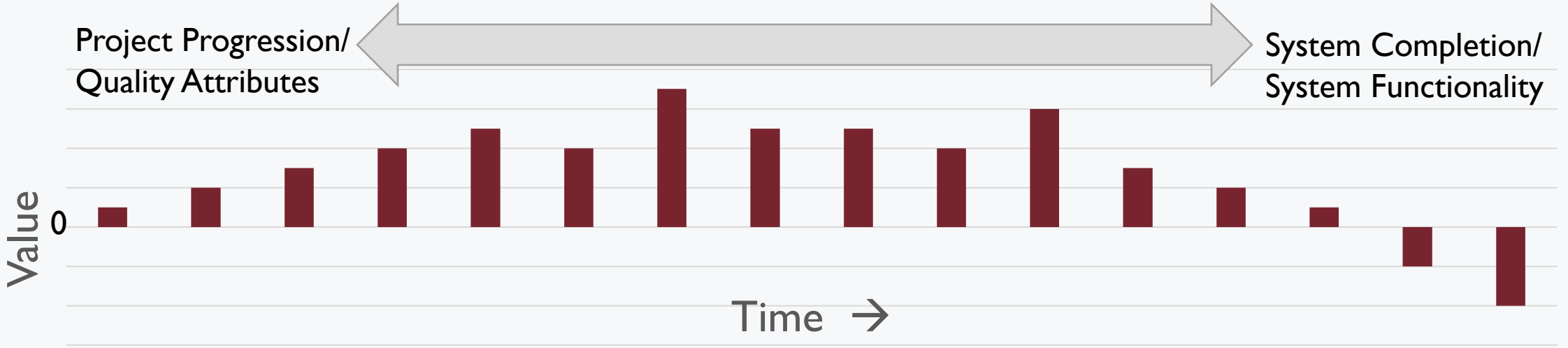


Net present value of the architecture for Stakeholder B from time period 5 to 16 (doesn't need to be 16, dependent on stakeholder B's expected lifespan of architecture at that time period)

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

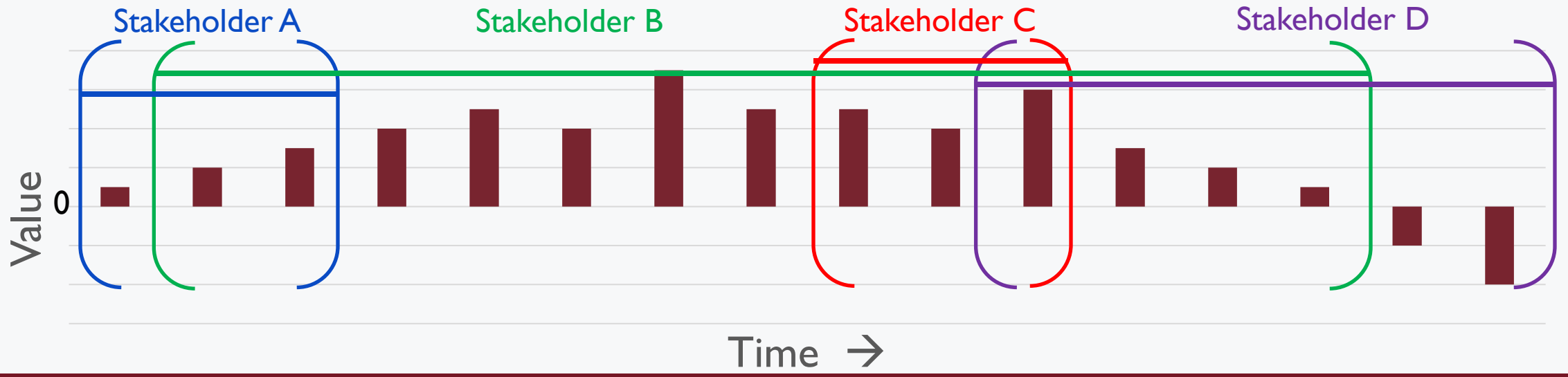
- RQ9: How to incorporate changing stakeholders?
- Preferences of stakeholders are likely to be different over time
- Early stakeholders may be more concerned with high-level architecture quality attributes
- Later stakeholders may be more concerned with system functionality enabled by the architecture



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 2: Determine Preferences on Architecture Outcomes

- RQ10: How to incorporate multiple simultaneous stakeholders? Open RQ
- Stakeholders may overlap along the architecture's time horizon
- At each time period the value is an aggregation of the stakeholders' values at that time period
  - Group decision-making techniques have assumptions and limitations
  - Game theory will be pursued due to fundamental rigor and previous engineering use

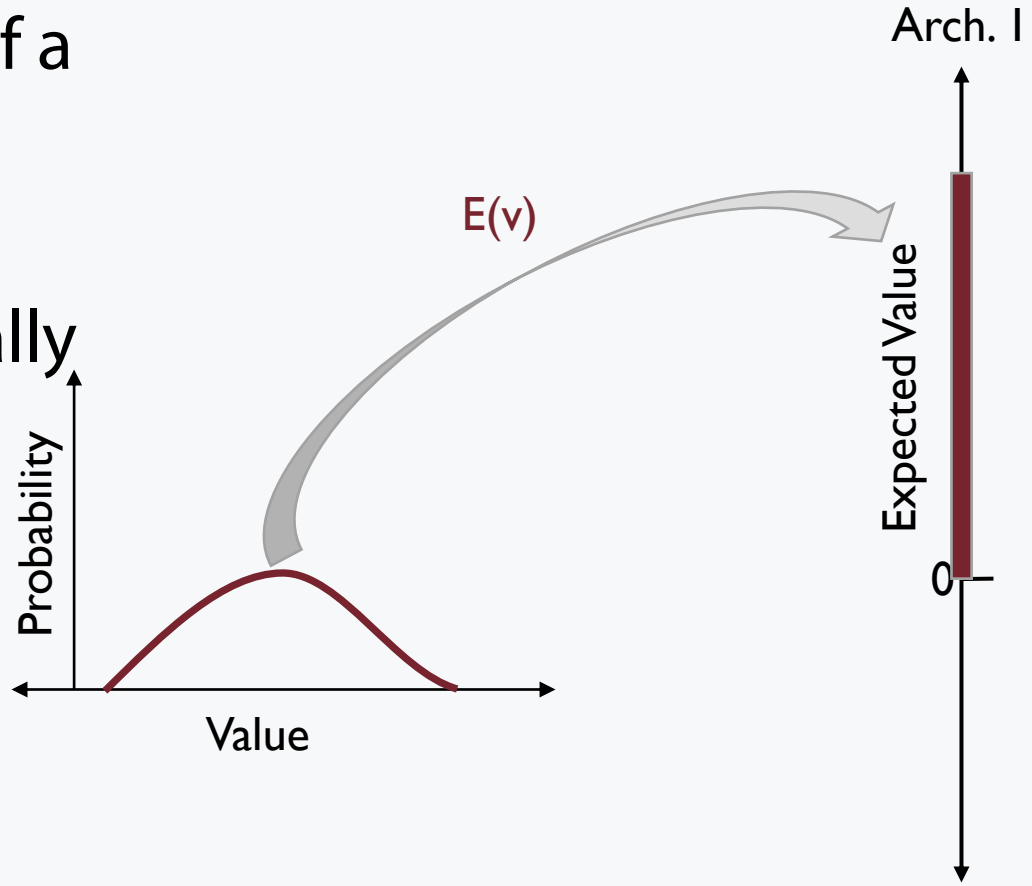


Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 3: Determine Beliefs present in Decisions concerning Architectures

- RQ11: How to incorporate uncertainty of a value at a specific time period?

- Represent uncertainty in a mathematically useful form – probability distribution
- Calculate Expected Value

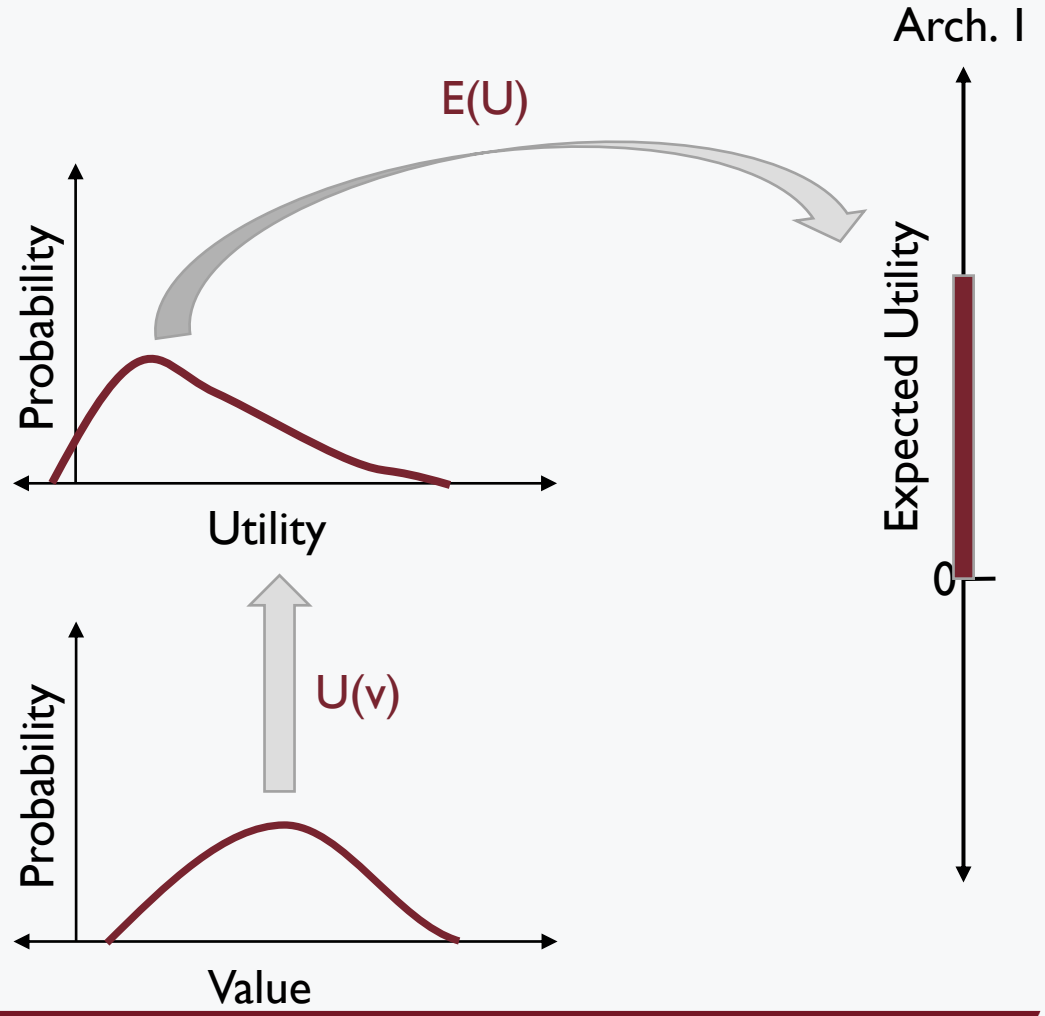


Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 3: Determine Beliefs present in Decisions concerning Architectures

- RQ11: How to incorporate uncertainty of a value at a specific time period?

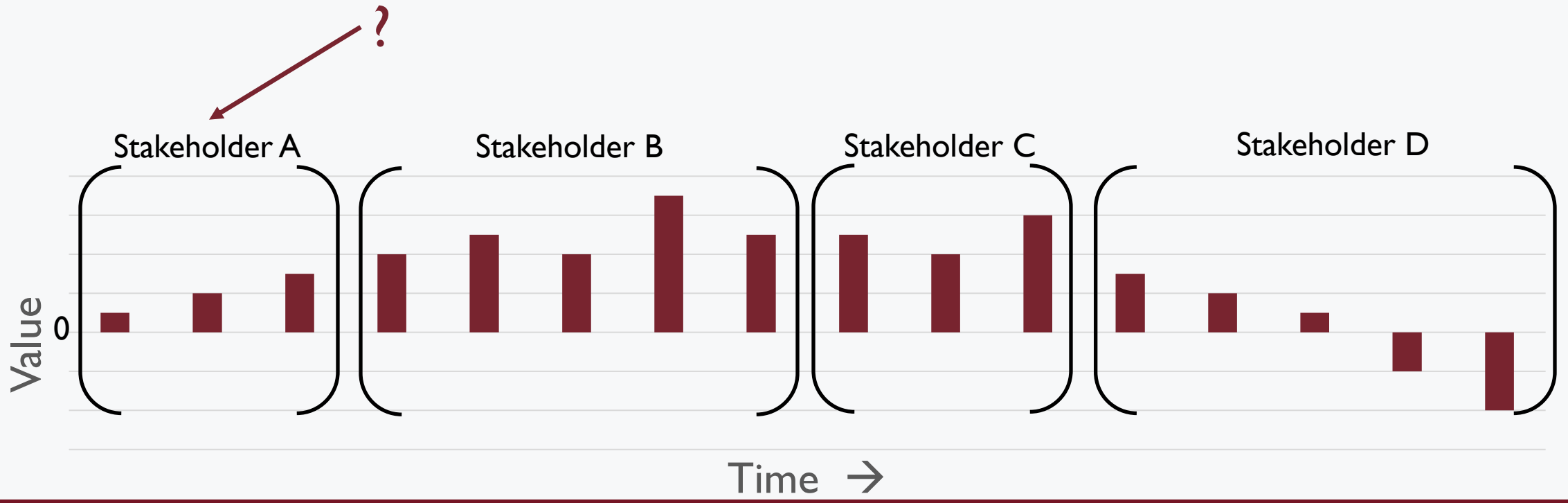
- But, what if stakeholders are not risk neutral?
- Determine stakeholders risk preference
- Then able to calculate and use expected utility



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 3: Determine Beliefs present in Decisions concerning Architectures

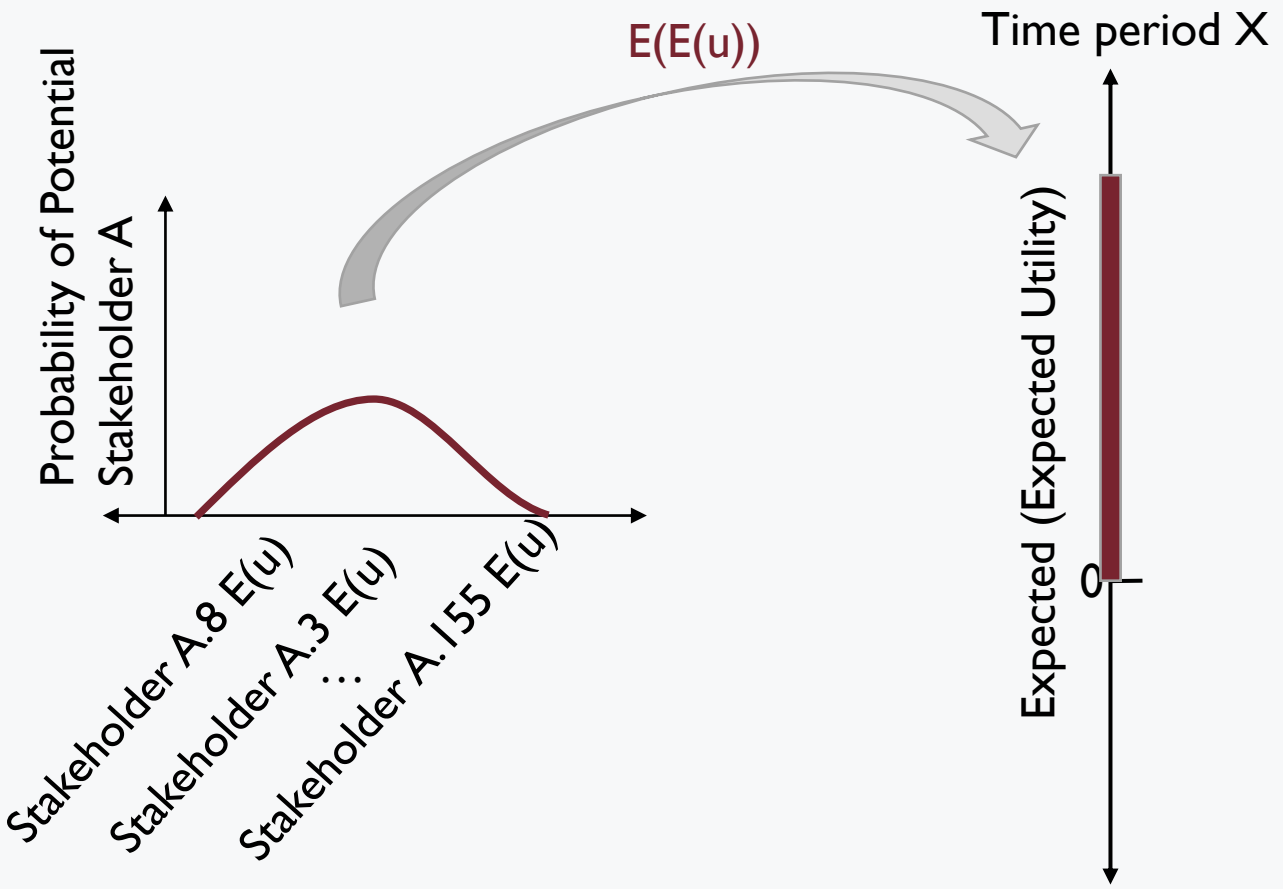
- RQ12: How to incorporate uncertainty of stakeholders?
- What if we are uncertain on what Stakeholder A's preferences are?
  - Could care about business drivers, flexibility, effort, etc.



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 3: Determine Beliefs present in Decisions concerning Architectures

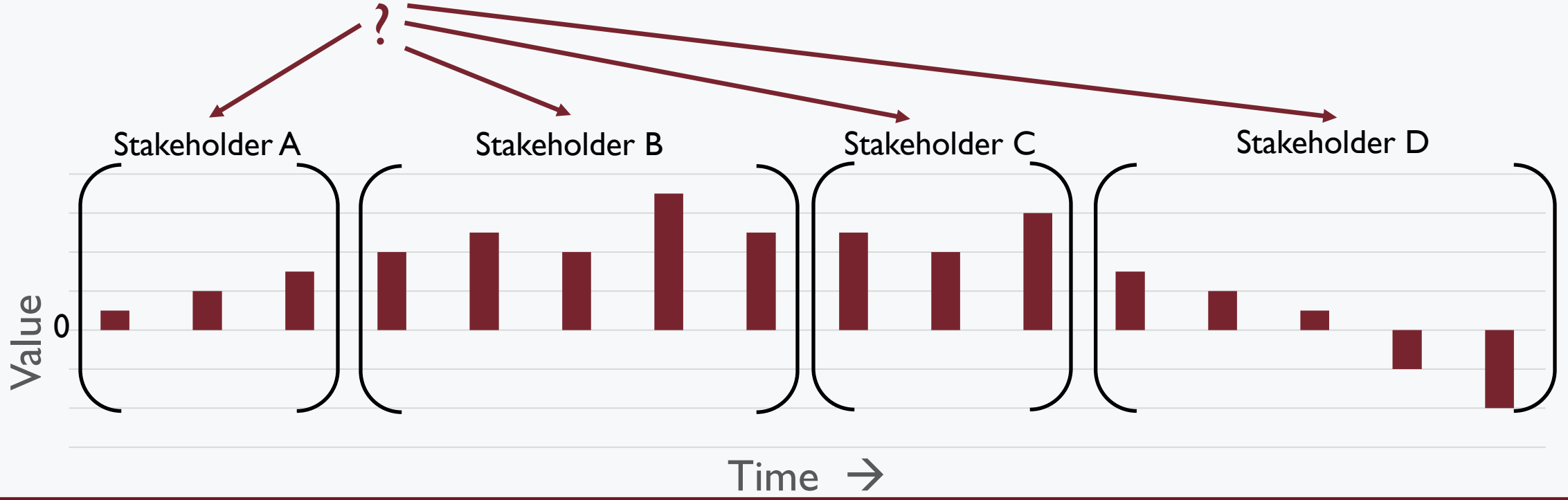
- RQ12: How to incorporate uncertainty of stakeholders?
- For each time period we can estimate potential stakeholders, the likelihood of those stakeholders, and their preferences
- Can also do expected utility calculation here from the perspective of the architect (not shown)
- Active research investigating rationality of using this technique in one-off scenarios



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 3: Determine Beliefs present in Decisions concerning Architectures

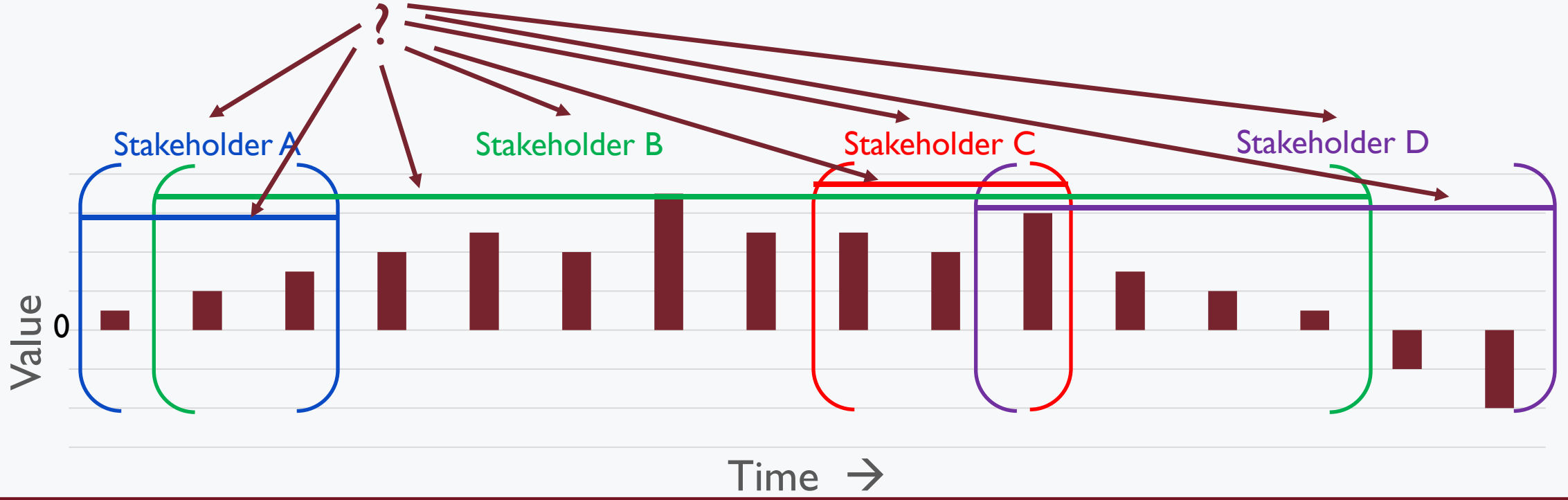
- RQ12: How to incorporate uncertainty of stakeholders?
- Can do same technique for uncertainties on combinations of multiple stakeholders



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 3: Determine Beliefs present in Decisions concerning Architectures

- RQ12: How to incorporate uncertainty of stakeholders?
- Can do same technique for uncertainties on combinations of multiple stakeholders and the time periods they influence

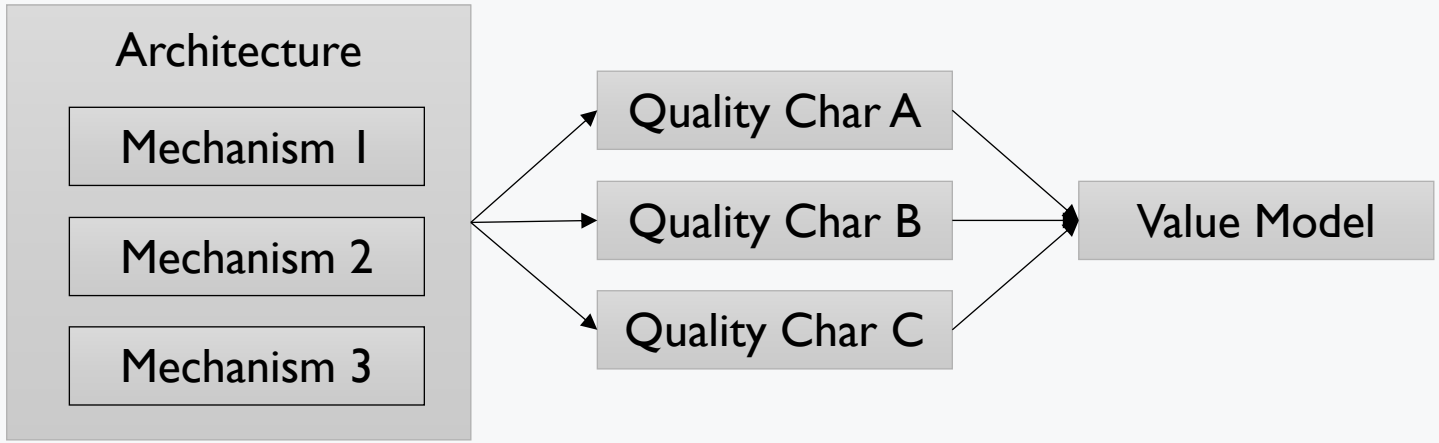


Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 4: Determine Architecture Alternatives

- RQ13: What decisions define an architecture?

- On going Army research is identifying mechanisms that can be used to define an architecture
- However, an exhaustive list is improbable and architects must be able to generate potential decision categories and decision alternatives



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

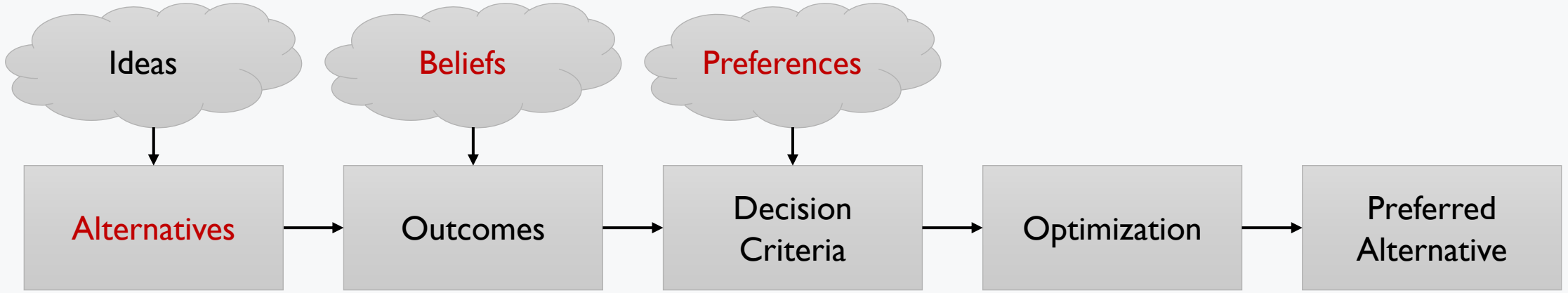
Step 5: Differentiating between Designing and Architecting

- RQ14: What properties of architecting make it unique from traditional design engineering?
  - The thing we are making decisions regarding is not easily measured
    - The architecture does not have a thrust, speed, weight, etc.
    - There is a lack of tools to analyze the architecture during the decision making process
  - Architecture decisions not only restrict future decision makers on the types of architecture and design decisions they can make, but also inform the decision makers on how to make those decisions
    - Restrict decision space AND the decision process
  - The time horizon is significantly long with extremely high uncertainties
  - There are many stakeholders along the time horizon that can significantly impact architectural decisions

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Step 5: Differentiating between Designing and Architecting

- RQ15: What do we have to change from design decision making to work for architecture decision making?
- The normative decision theory approach used in traditional design engineering is unchanged
- The challenge is solely in the formation and representation of the alternatives, beliefs, and preferences



Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Future Work

- Preferences
  - Interviewing/surveying architecting community to understand their preferences
  - Interviewing/surveying architecture stakeholder community to understand their preferences
  - Study to determine best techniques for transforming different preference measures to a common scale
  - Study to determine best technique for aggregating multiple stakeholder preferences at a specific time period
- Beliefs
  - Interviewing/surveying architecting community to understand their risk preferences
  - Interviewing/surveying architecture stakeholder community to understand their risk preferences
  - Study to determine sources of uncertainty in outcomes and ways to measure them
    - Unknown warfighting environment
    - Unknown changes in elected official desires
    - Unknown future technologies and their readiness
    - Etc.
- Alternatives
  - Formulate a methodology for generating new decision alternatives
- Validity of information sources
- Sufficient documentation of decision to justify to current and future stakeholders

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

Future Work

- Persistent Question:

- Is architecting so uncertain that dominant decision strategies emerge which enable more heuristic or axiomatic -based decision processes?
  - Normative decision analysis would say that when different preferences are possible it is unlikely that dominant strategies for all of those preferences exist.
  - However, this is an open question that will be formed through experimentation.

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.

SYSTEMS ENGINEERING RESEARCH CENTER

THANK YOU

Stay connected with us online.

Distribution Statement A: Approved for Public Release. Distribution is Unlimited.