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Title: Mitigating Value Mismatch at the Dynamic Interface of Stakeholder Preferences and Systems Options

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Mitigating Value Mismatch at the Dynamic Interface of Stakeholder Preferences and System Options

Research Overview

Change is inevitable, both in reality and perception. Developing robust systems to deal with real-world changes has been advanced through such approaches as Axiomatic Design and Taguchi Robust Design methods (Suh 2001) (Park 1996). The goal of system design is not robust systems per se, but rather the delivery of value to system stakeholders. Dealing with value mismatch, including perception changes, has not been dealt with in the same manner as classical notions of robustness. It is inevitable that decision makers change their mind, and therefore their perception of value of a system. In order to maintain value delivery over a system lifecycle, a system must change to match new decision maker preferences. If system designers could anticipate or account for changing preferences when designing products or services, they would be empowered to create more valuable systems over time.

Dynamic Multi-Attribute Tradespace Exploration (Dynamic MATE) is a design approach to account for changeability and unarticulated value (Ross 2006). While introduced as a dynamic value creating design response to changing value perceptions, more research needs to be done to properly characterize when, how, and why value perceptions change and more importantly, when, how, and why systems appear to fail to deliver value to stakeholders.

Three phases of research are needed to address the critical problem of value mismatch in design. These phases include 1) characterization of value mismatch and extension of Dynamic MATE to enhance Design for Changeability, 2) development of theoretical value mismatch framework, 3) development of case studies. Through the completion of these phases, designers will be empowered to identify, anticipate, and respond to cases of value mismatch, thereby mitigating potential for lost value and increasing overall system lifecycle value delivery.

Characterization of Value Mismatch and Extension of Dynamic MATE to Enhance Design for Changeability

Develop characterization framework for identifying cases of value mismatch between decision maker preferences and system design instantiations. Extend Dynamic MATE analysis techniques to incorporate potential system design responses to value mismatch potential.

The goals of this research phase include the following:

1. Characterize sources and factors of value mismatch (including time variation of system decision maker preferences)
2. Develop visual "storyboard" vehicles for communicating value mismatch concepts
3. Extend Dynamic MATE approaches for Designing for Changeability in order to maintain value delivery over system lifecycle
4. Identify historical system examples of value match/mismatch for validation studies

Development of Theoretical Framework

Develop theoretical framework and constructs for anticipating and mitigating value mismatches during the design process

The goals of this research phase include the following:

1. Using a synthesized theory of value mismatch, develop a mathematical frame for predicting dynamic preferences
2. Develop rigorous quantitative framework for analyzing system timelines for maximizing lifecycle value and selecting "best" tradespace design options during Conceptual Design
3. Validate value mismatch framework through historical analysis of real systems

Deployment of Research through Pedagogical Means

Develop case studies and workshop materials to facilitate deployment and use of phase I and II research results

The goals of this research phase include the following:

1. Develop formalized case studies for classroom deployment illustrating the value mismatch and Design for Changeability frameworks
2. Organize a workshop for disseminating research results to academia, government, and industry

Goals

A guiding principle for the development of Multi-Attribute Tradespace Exploration (MATE) process is for it to be a "natural" process that includes holistic consideration of design issues built from fundamental concepts to promote good system design techniques without dependence on expert knowledge or experience. Good design should not be the sole province of the rare star system designers with decades of experience, but rather the product of proper training in the fundamentals of system design. A holistic, foundationally strong system design methodology will streamline the teaching of advanced system design concepts and empower the next generation of design engineer.

Another goal for the process development is the creation of simple visual representations for the fundamental concepts of system design and value creation. Dr. Ross found in the course of field research and interaction with technical experts and senior decision makers that simple visual "storyboards" resonated more strongly for communicating concepts than abstract mathematical frameworks or jargon-laced discussions. Pictures encapsulated many complex concepts in efficient space and transcended terminology disagreements.

Often unknown value propositions are treated as random or unknown quantities (e.g. random utility in decision theory, discrete choice analysis in operations research). It is hypothesized that underlying structure exists for classifying and predicting value changes. The current research proposal will attempt to make progress on that issue through synthesis across various disciplinary approaches and original theoretical contributions.[1] The characterization framework

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[1] Examples of disciplinary approaches include:
Finance: market volatility (pricing) → descriptive framework for changing group preferences

for preference volatility (changing value propositions over time) will be validated through the study of real cases. Empowered designers, able to predict or anticipate how value will change over time, will be able to create value-sustaining system designs.

Prior Research

The proposed research will seek to leverage the prior research into value-driven system design, using Multi-Attribute Tradespace Exploration described by (Ross, Diller et al. 2004) and later extended by (Ross 2006) with Dynamic Multi-Attribute Tradespace Exploration.

Multi-Attribute Tradespace Exploration

Let us suppose that the following statement captures the goal of design:

Create a system that fulfills some need while efficiently utilizing resources within some context

Traditional design approaches either begin with a need or a pre-conceived system and attempts to fill in the remaining goal elements.[2] Figure 1 shows a graphical depiction of the goal and the key terms. The context surrounds the entire endeavor, including the roles of participants and their domain of influence. The Stakeholder role includes influence over the definition and evaluation of the needs. The Funder role includes influence over and allocation of the resources. The Decision Maker role acts as the gatekeeper of needs and resources, determining whether to pursue a system development effort.[3] The Designer role includes influence over the definition of the system, while efficiently utilizing resources and fulfilling needs, as determined by the Decision Maker.

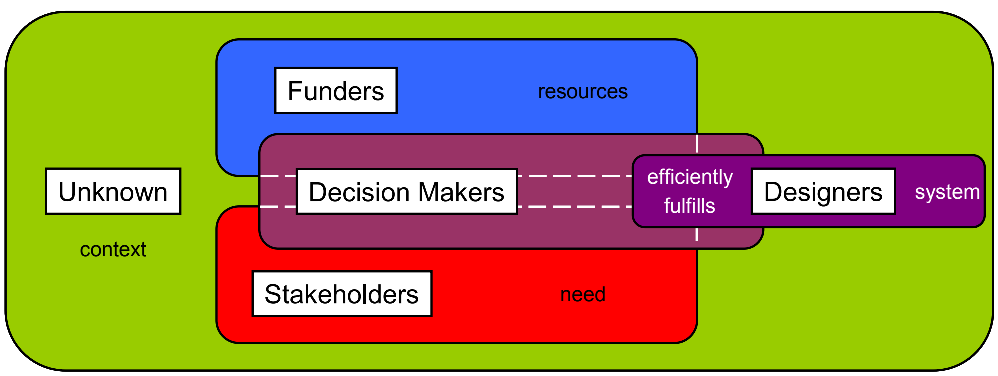


Figure 1 The goal of design

Economics: consumption volatility → descriptive framework for changing individual and group preferences
Political science: voter volatility→descriptive/prescriptive frame for individual and group preferences
Social psychology: group polarization→causal/descriptive frame for individual changing preferences
Engineering design: requirements prioritization, robust design → dealing with changing preferences
Decision theory: stochastic, random utility models → approximating changing unknown individual and group prefs

[2] Examples of these two approaches are "market pull" and "technology push."

[3] The existence of multiple decision makers, or any other role, adds to the complexity of the design problem space. Multiple decision makers may jointly, or separately, have the power described here, working cooperatively or competitively to achieve their aims. Ideally the design endeavor is cooperative, but reality may not provide such a rosy scenario. Strategic behavior can occur among stakeholders or stakeholders and funders in order to make themselves better off, sometimes at the expense of others. Such behavior can obfuscate the real value propositions for people, or reduce the options space, preventing the discovery of designs that could make everyone better off.

Multi-Attribute Tradespace Exploration (MATE) focuses on Decision Maker derived need as a driving force for the design activity. Decoupling the design from the need through tradespace exploration, MATE is both a solution-generating, as well as decision-making framework (Keeney and Raiffa 1993). Driven by the concept of value-driven design (Keeney 1992), MATE uses rigorous decision theory applied to the system engineering and design problem, as suggested by (Hazelrigg 1996), while avoiding the limitations of other approaches, such as Axiomatic Design (Thurston 2001). At a high level, the MATE process has the three following layers: Need Identification, Architecture-level Evaluation and Exploration, and Design-level Evaluation and Exploration. ((Ross, Hastings et al. 2003) introduces MATE at a high level and (Ross 2003) describes the steps of MATE in detail.)

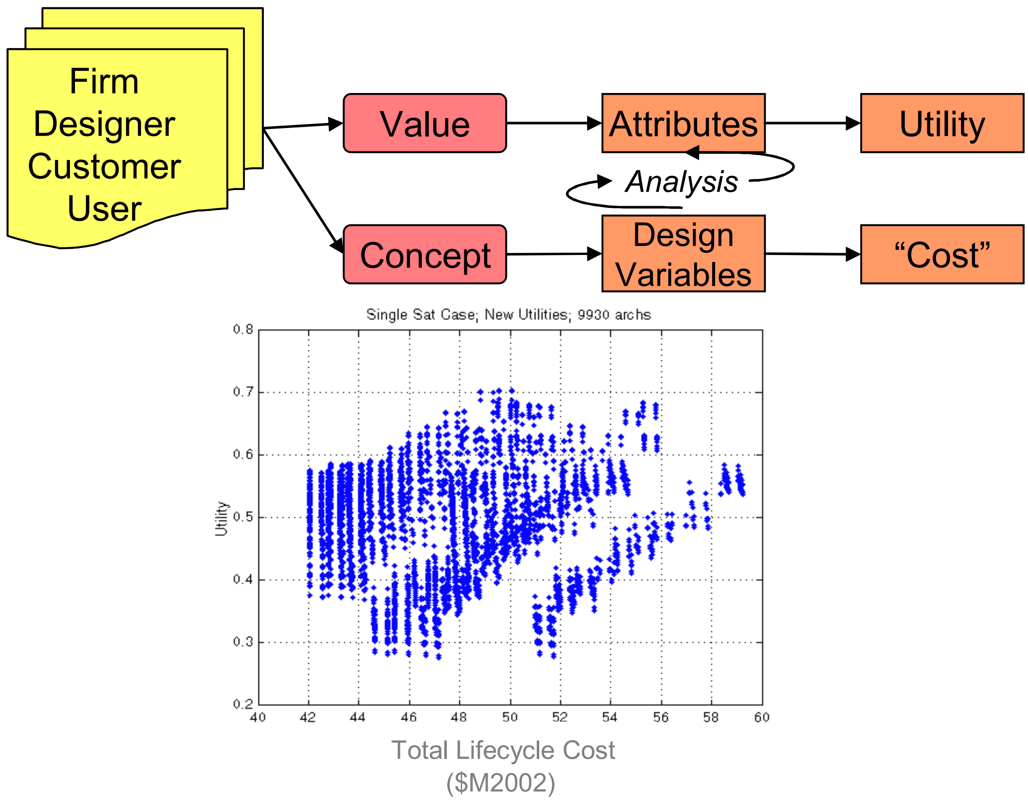


Figure 2 MATE process flow from stakeholders to tradespaces

Figure 2 shows the high level activities in the MATE process.[4] Stakeholders, or decision makers, including such roles as Firm, Customer, and User, express their value propositions in terms of quantifiable metrics, the attributes. The aggregate value of the attributes for a particular decision maker is captured in terms of an elicited utility function. Generated by the designers, concepts are parameterized in terms of design variables, which are varied and assessed through analysis in terms of their attributes. The cost of creating the designs, and the utility generated from their realization are plotted in a utility-cost tradespace for exploration of benefit-cost tradeoffs. The advantages to exploring design options using tradespaces is discussed in (Ross and Hastings

[4] MATE includes elicitation of value in terms of attributes from stakeholders, and focuses the generation of concepts in terms of alternative designs parameterized by design variables. A multitude of designs are assessed in terms of benefit perceived and resources required (utility and cost respectively) and are explored in a tradespace framework.

2005) and includes discovery of the structure of mappings from design space to value space, illustrating to designers how changes in design result in changes to value delivered.

The MATE process was proposed and developed through the two Masters theses of (Diller 2002) and (Ross 2003). MATE was applied to various case studies including real world systems, such as the Small Diameter Bomb (Derleth 2003) and the Space-Based Radar (Spaulding 2003), as well as to framing the Spiral Development model for system acquisition (Roberts 2003) and for commercial system portfolio development in an enterprise (Stagney 2003). (Shah 2004) used data from a MATE study as part of research into using modularity for evolutionary acquisition of the Space-Based Radar, while (Seshasai 2002) described the knowledge capture and sharing aspect of MATE through interview artifacts created during utility interviews with decision makers and the resulting design decisions made by a MATE designer. (Ross 2006) synthesized the various MATE research, and introduced consideration for expanded notions of value including unarticulated value and dynamic contexts, as well as a taxonomy and mental constructs for considering changeable designs.

From Articulated to Unarticulated: Spectrum of Perceived Needs

The value created by a developed system can often be placed into two categories: driving need, or derived need. Driving need exists before the system is developed and provides the impetus for the development effort. Derived need emerges from the system in operation, revealing itself to those affecting and affected by the system. From the perspective of the initial system Designer who seeks to create a valuable system, the driving need is often expressed in terms of objectives and requirements, while the derived need is expressed through marketing research and business strategy. A key difficulty presented by derived needs to the Designer is the uncertainty associated with it. Instead of viewing the needs in terms of these two categories of driving and derived, a more useful taxonomy is to consider value as a spectrum of needs from articulated to unarticulated.

Imagine there exists a set of needs for every system stakeholder past, present, and future. If a system designer could know these needs and provide a way for the system to meet them in the correct manner at the correct time, such a system would be valuable indeed. Articulated needs are those needs from the set that have been explicitly communicated to the system Designer. Unarticulated needs are those that have not yet been explicitly communicated. The reasons for the unarticulated needs are various, but the goal of the Designer is the same: discover as much of the unarticulated needs as possible, or at least make it so the system can meet them when they are revealed or discovered.

Unarticulated needs include those that cannot be explicitly communicated because the stakeholder has forgotten them for the moment, or does not yet know them, or cannot quite express them in words. Unarticulated needs also include needs that stakeholders do not say because the stakeholder has assumed that the Designer is already aware of them. Additionally, unarticulated needs include those needs the stakeholder will not say because, for whatever reason, those needs must remain secret. The reasons for the unarticulation may change over time as well.

Economists and business analysts typically use market valuation techniques, such as viewing price elasticity of demand to determine how much money people are will to pay for a good or service as a proxy for aggregate unarticulated value, also known as revealed preferences. (Cook and Wu 2001) is an example of using this technique to motivating the selection of best design alternatives. Aggregate valuation techniques are useful when data is readily available over many individuals. For the design of unique or customized systems however, direct techniques, such as interviews, are more appropriate, though an interviewer must be aware of cognitive biases and inconsistencies of how individuals perceive value and how those values may change due to the influence of others (Whyte 1998; Kahneman and Tversky 2000).

The process of revelation or discovery of an individual's unarticulated needs can incorporate several methods including personal reflection, conversations with mediators, experience with the system, interactions with the system context, or seeing the system in a changed or new context (Durgee 2001).

Role of Dynamic Context

A common approach in system design is to optimize the system according to a set of objectives. Finding the "best" system is the goal of such an exercise. The technocratic optimization approach works well and will provide the "best" answer only if the assumptions of the analysis hold true in the real world. Unfortunately, often such is not the case. A fundamental assumption in the optimization approach is the assumption of correct objective functions. If the objective functions change with time, no guarantee exists that the system will remain "best". In fact, recent research suggests that such overly optimized designs are quite fragile in the face of changing objectives or context (Carlson and Doyle 2000; Zhou and Carlson 2000).

Related to the assumption of static objectives is that of static context. Design for Robustness is an approach to try to find design options that will continue to perform well in the face of changing operational environments. The context includes not only the operational environments however, but also the stakeholder sets, the expectations of the system, the resources available to the system, the competition for the system, and any other exogenous factor that affects the perceived value of the system. Many of these factors are not considered during an optimization exercise beyond the technical environment, though they may significantly affect the perceived value of the system. An example of such a dangerous omission is a technical optimization of a satellite-based communication system, ignoring terrestrial competition, such as the fate suffered by the Iridium and Globalstar satellite systems.

In the military regime, high-level objectives may remain relatively static, such as 'defend some region,' or 'provide information about some region.' As these objectives are decomposed, however, assumptions begin to creep in, which also inherently includes the possibility for change. An example is the emerging usage of UAVs for both rapid reconnaissance and interdiction, or the growing civil dependence on the military GPS system. On even shorter time scales, targets of opportunity arise and systems must react quickly in order to deliver value, even if the desired usage does not match the intended usage. In order to capture value, as it emerges from unarticulated to articulated space, systems must be designed for changeability.

Changeability: Reconciling Flexibility and other Ilities

The motivation for changeability over a system lifecycle is categorized into three major drivers according to (Fricke and Schulz 2005): 1) dynamic marketplace, 2) technological evolution, and

3) variety of environments. These drivers result in two key aspects for system architecture to address: 1) they must be able to be changed easily and rapidly, and 2) they must be insensitive or adaptable towards changing environments. Such notions are often referenced in discussions of “flexibility” and “adaptability” and are often found in the manufacturing literature (Giachetti, Martinez et al. 2003). Recent work has tried to synthesize these definitions into a prescriptive six-element framework in the space system domain (Nilchiani 2005). Instead of focusing on individual “ilities,” (Ross and Hastings 2006) and (Ross, Rhodes et al. 2007 (submission Oct 06)) show that flexibility and adaptability are subset concepts within changeability itself and describe particular types of changes.

Summary of Key Prior Research Contributions

The key contributions of (Ross 2006) Dynamic MATE can be summarized in six main categories.

1. A unified definition of six system properties (ilities)

The six ilities considered in Dynamic MATE are shown to be different aspects of the same concept: changeability. (Figure 3 below reviews the concept of changeability.) Flexibility and adaptability relate to the origin of the change agent: external or internal to the system boundary, respectively. Scalability and modifiability relate to changes in levels or sets of system parameters, respectively. Robustness cast as “value robustness” relates to maintaining value delivery in spite of changes within or without the system. Robustness can be pursued either through passive robustness (choosing a good design that does not need to change), or active robustness (choosing a design that can be altered to continue to deliver value over time).

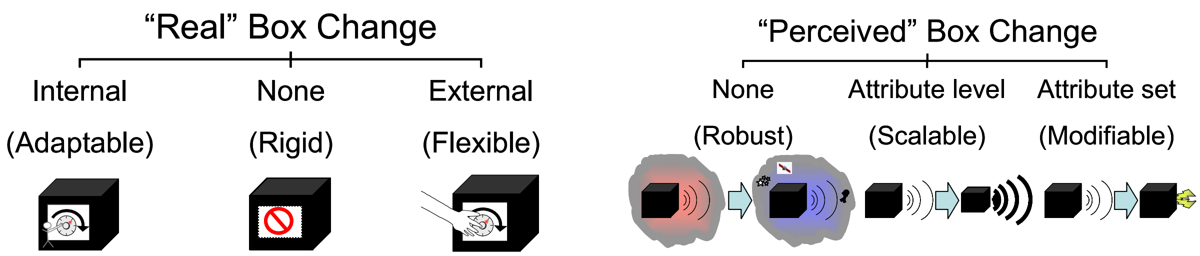


Figure 3 Aspects of changeability: adaptability, rigidity, flexibility, robustness, scalability and modifiability

2. Quantification of flexibility/adaptability/robustness/scalability/modifiability

As aspects of changeability, flexibility/adaptability/scalability/modifiability can be quantified as the Filtered Outdegree of a particular design in a tradespace network generated by transition rules (see Figure 4 below). The outdegree reflects the number of possible change paths from a design’s current state to possible future states. The filter is the subjectively set acceptability threshold that varies from decision maker to decision maker, capturing the inherent subjectivity of changeability perception. Only paths “costing” less than the acceptability threshold are counted when determining the Filtered Outdegree. A change in subjective perceptions, increases in change mechanisms (transition rules), or decreases in cost for change all can increase the perceived changeability of a system.

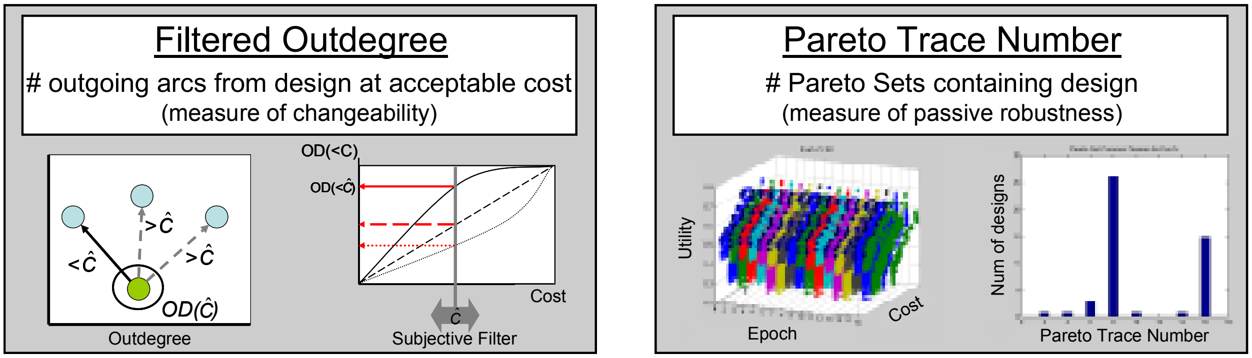


Figure 4 Filtered Outdegree and Pareto Trace Number definitions

Passive value robustness can be quantified as the Pareto Trace number, which is the number of Epochs (or scenarios) whose Pareto Set contains that particular design, reflecting the designs that have the most efficient utility for a given level of resource expenditure (see Figure 4). A relatively large Pareto Trace number implies a high passive robustness factor for a particular design and can be a function of excess capability, insensitivity to the particular change scenario, or a locally stable region in a tradespace.

3. Framework for representing unarticulated value

In addition to the typical articulated value, captured in explicit communication between decision makers and system designers, a spectrum of value exists. Unarticulated value includes those current and potential aspects of a system that result in value to a decision maker, but have not been explicitly communicated. Differentiating between the articulated and unarticulated value in terms of "cost to display" in the system results in five attribute classes (see Table 1 below). The "display" of an attribute means that the system "is" or "does" the attribute.

Table 1 Attribute class definitions

Class	Name	Property of Class	Cost to Display
0	Articulated Value	Exist and assessed	0
1	Free Latent Value	Exist, not assessed	0
2	Combinatorial Latent Value	Can exist by recombining class 0 and/or 1	Small
3	Accessible Value	Can be added through changing {DV} (scale or modify)	Small→large
4	Inaccessible Value	Cannot be added through changing {DV} (system too rigid)	Large→infinite

Class 0 attributes are the "articulated value" and include those value metrics that are explicitly used to design the system. These attributes are "free" to display since the system already addresses them. The rest of the classes are types of unarticulated value. Class 1 attributes are "free latent" value, representing aspects of a system already being displayed, but not asked for by the decision maker. If that attribute becomes value generating, it is "free" for the system to display it. Class 2 attributes are "cheap latent" value, representing aspects of the system that can be created through a simple recombination through an interpretation mechanism. The system itself does not require change, only the interpretation of the existing displayed attributes. Class 3 attributes are "accessible" value, representing attributes that could be displayed through a change to the system. The cost for the articulation of class 3 attributes ranges from cheap to expensive. Class 4 attributes are "inaccessible" value, representing attributes that cannot be displayed by the system due to excessive cost or the existence of constraints. These attributes are better displayed in a different system.

4. Framework for discovering "efficient" solutions for multi-stakeholder negotiations

The multi-decision maker tradespace exploration proposed in Dynamic MATE results in a set of designs that can be used as the basis for negotiation. The single decision maker Pareto Set solutions represent the most "efficient" usage of resources for creating value for that particular decision maker. The Joint Pareto Set is the multi-decision maker analogue and captures the individual Pareto Set solutions as well as "compromise" solutions that trade between the decision makers. (Figure 5 below gives the Joint Pareto Set example from X-TOS analyzed in Chapter 7.)

Designs in Joint Pareto Set

DM1 Pareto Set DM2 Pareto Set Compromise Pareto Set

903	919	920	933	935	936	951	952	965	967	981
982	983	984	997	1687	1703	1735	1749	1751	1765	1767
1781	2471	2487	2501	2503	2519	2533	2535	2549	2551	2565
4511	4515	4531	4535	4536	4539	4540	4555	4556	4559	4560
4563	4564	4579	4580	4583	4584	4587	4588	4603	4604	4607
4608	4611	4612	4627	4628	4631	4632	4633	4707	4708	4727
4728	4747	4748	4771	4773	4795	4796	4797	5687	5691	5707
5711	5715	5731	5735	5739	5755	5759	5779	5783	5787	5803
5807	5809	5883	5903	5923	5947	5949	5971	5973	6863	6867
6883	6887	6891	6907	6911	6915	6931	6935	6939	6955	6959
6963	6979	6983	6985	7059	7079	7099	7123	7125	7147	7148
7149										

Joint Pareto size: 122 designs

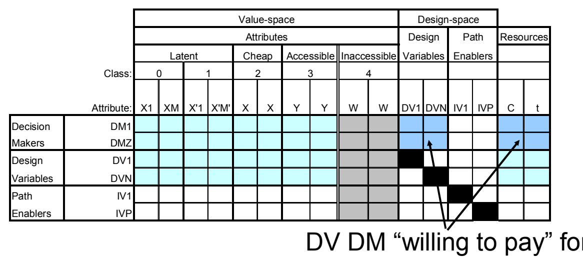


Figure 5 Example Joint Pareto Set for X-TOS, including overlapping "best" designs in white, and Design-Value Matrix used for analyzing cost-benefit distribution among decision makers

Knowledge of the structure of the tradespace, as well as the Joint Pareto Set enables decision makers to understand the key trades between their value propositions and whether an acceptable compromise solution can be found. The distribution of costs and benefits (resources and utility) can also be illustrated through this process, helping decision makers to discover key tensions in the interpersonal comparison of utility, which cannot be done in an arbitrary fashion. (See Figure 5 for a notional example using the Design-Value Matrix for distribution of costs and benefits.)

5. Framework for considering "Design for Changeability"

The usage of Design-Value Matrices, Rule-Effects Matrices, and Outdegree Assessments help focus the attention of designers on the effects of change on the value propositions of decision makers, as well as the effect on the system design parameters. (Figure 6 below: Design-Value Matrix.) Explicit attention to the creation of "Path Enablers" reveals design choices that create value not through their effect on attributes, but rather through their effect at enabling change (through the generation of additional change paths, or their reduction in cost of change path). The Path Enablers can be traced through their effects on design parameters to attributes and subsequently to the decision makers. In this way, designers can better understand "who might care about modularity" and therefore be willing to pay for it. The change enabling nature of these concepts can be used as a strategy for reducing long run change costs within an organization, as shown in the JDAM case application.

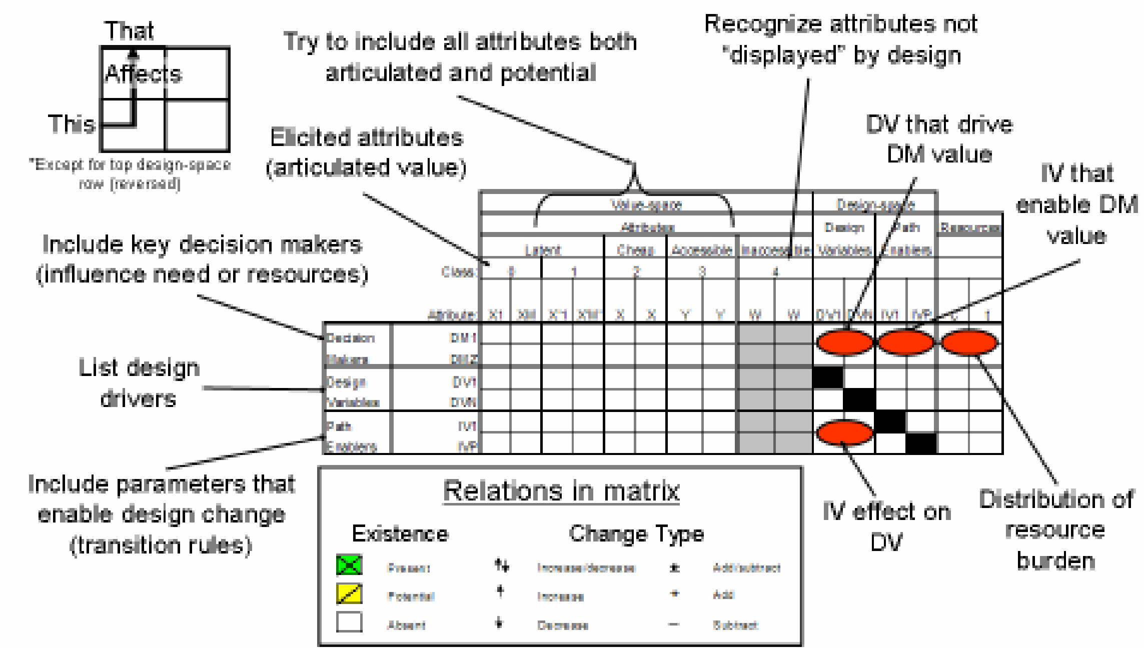


Figure 6 Design-Value Matrix defined

6. Application of Dynamic MATE to two real systems

The Joint Direct Attack Munition (JDAM) and the Terrestrial Planet Finder (TPF) were studied through the Dynamic MATE lens and shown to address changeability in very different ways. (See Figure 7 below for example tradespaces.) JDAM, as an actual system in use, was shown to be a highly changeable system due to its use of three key path enablers: modularity, commercial off-the shelf (COTS) parts, and simple, excess capacity interfaces. Along with its simple design, these path enablers have allowed the system developers to continuously upgrade and refit the system over time, offering several "accessories" to customize the system to customers, all while maintaining a high level of program success. The JDAM was shown to not only be a changeable system itself, but also a path enabler to flexible and adaptable missions.

TPF, a major space-based astrophysical observatory seeking to characterize extrasolar planets for their potential for life, is aiming for deployment early next decade. The conceptual design phase for this system is ongoing and the architectures under consideration have slowly changed with time, as have the requirements. Since the science aims may change with time, the system itself must be able to change, or have excess capability in order to meet the various demands placed on it. Finding a passively robust TPF architecture may not be possible, as the current set of requirements may not be readily met with a single architecture considered by this study.

The pressure to combine science goals of distinct communities may result in a reduction in the feasible space of design options to a null set. Coupled with detector technological progress, the TPF mission may benefit from waiting before further development as system designers seek to elucidate the key tensions between science goals, available resources, and technical capabilities.

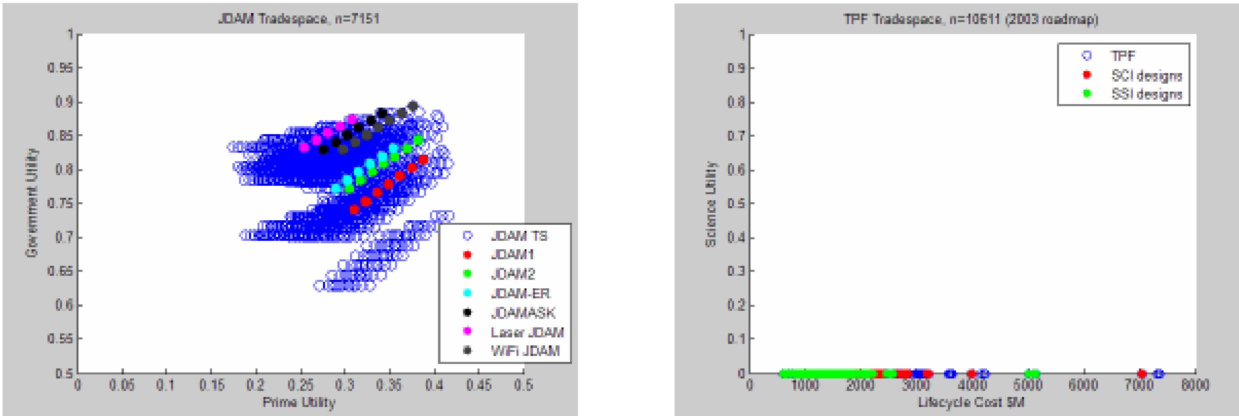
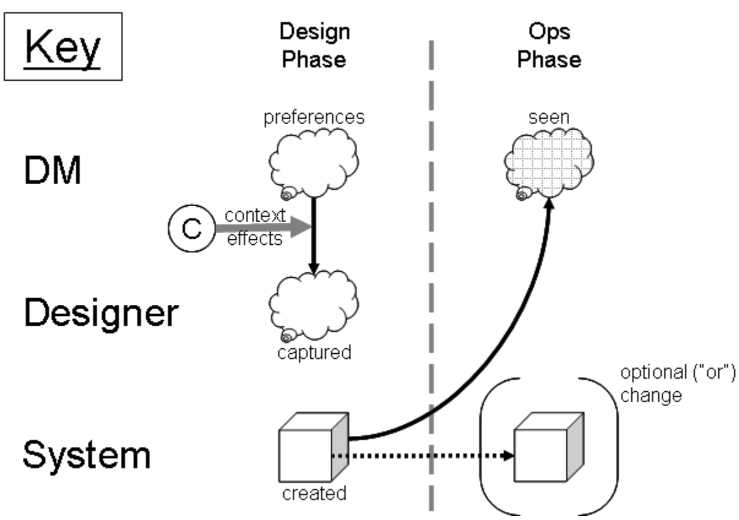


Figure 7 JDAM and TPF tradespaces

Not only can the precursor MATE work each be seen as special cases of the generalized Dynamic MATE approach, but also system properties, the "ilities," have been defined within a unifying framework for their consideration during Conceptual Design. It is only when designers have a good grasp of the dynamic flow of value that they can develop truly long-lasting valuable systems. The role of a good designer is not about technical achievement, but about value creation and sustainment.

Dynamic MATE is presently being further validated through case applications with AFOSR in collaboration with research partners. Several areas have been identified for further development. One of these is to extend the theory and methods for anticipating and mitigating value mismatch.



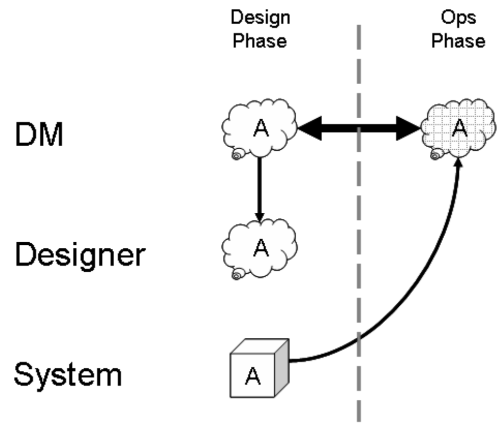
Value Mismatch Cases

The motivation for Design for Changeability is to develop systems that can match displayed characteristics with expected characteristics that are value perceived by decision makers. Six cases for value match/mismatch have been identified and will be developed through the proposed research.

Each of the cases will be depicted in terms of the figure to the left. The Decision Maker (DM) holds preferences, through which value is perceived. The system Designer captures some set of preferences in order to motivate the system creation (through requirements, for example). The System is created and displays some characteristics (form and or function) that are value-perceived by the DM when in operation. The figure splits the system lifecycle into prior to deployment ("Design Phase") and after deployment ("Ops Phase"). The "seen" characteristics may or may not match the "preferences" of the DM. A match would imply value perception, while a mismatch would imply value lost or missed. The "context effects" include DM/Designer/System exogenous influences on the flow of information, design, and value.

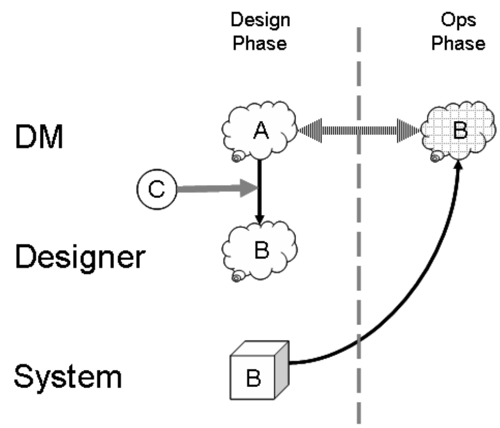
Case 1: Static Match

The first case is one of static value matching. The DM has preference set "A" and the Designer captures a set "A," which then directs the creation of a System that displays "A." In operation, the System is seen to display "A," which matches the preference set of the DM and thereby creates a value match.



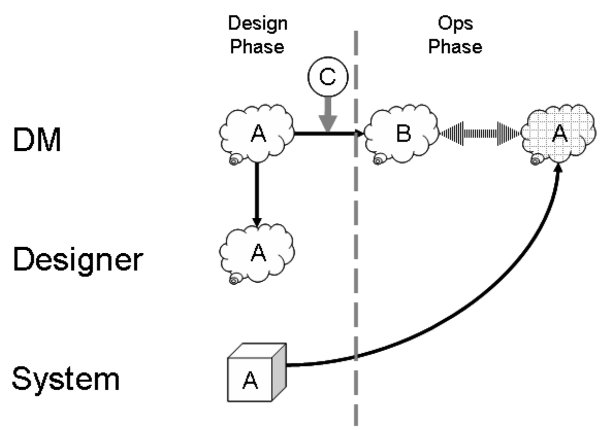
Case 2: Elicitation Failure

The second case is one of elicitation failure. The DM has preference set "A" and the Designer captures a set "B," which then directs the creation of a System that displays "B." "Context effects" may interfere with the preference elicitation. In operation, the System is seen to display "B," which does not match the preference set of the DM, "A" and thereby does not create a value match.



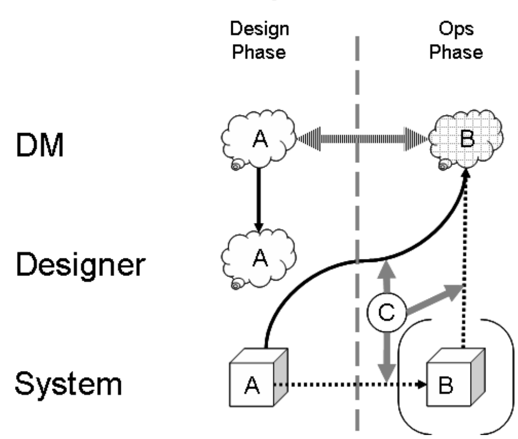
Case 3: Preference Change

The third case is one of preference change. The DM has preference set "A" and the Designer captures a set "A," which then directs the creation of a System that displays "A." "Context effects" may have a role changing the DM preference set at some point prior to or after operations begin. In operation, the System is seen to display "A," which does not match the preference set of the DM, "B" and thereby does not create a value match.



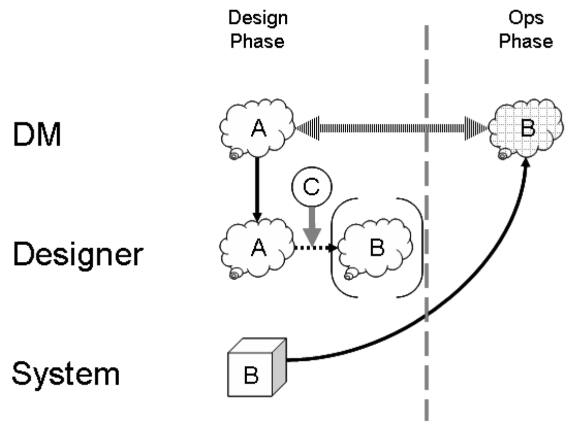
Case 4: Perception Failure

The fourth case is one of perception failure. The DM has preference set "A" and the Designer captures a set "A," which then directs the creation of a System that displays "A." "Context effects" may have a role changing the System display characteristics or at least how the characteristics are seen by the DM. In operation, the System is seen to display "B," which does not match the preference set of the DM, "A" and does not create a value match.



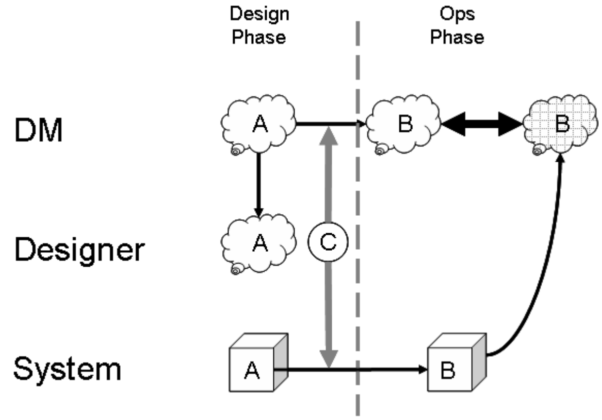
Case 5: Design Failure

The fifth case is one of design failure. The DM has preference set “A” and the Designer captures a set “A.” “Context effects” may have a role changing the Designer captured preferences at some point prior to or after operations begin which then directs the creation of a System that displays “B.”. In operation, the System is seen to display “B,” which does not match the preference set of the DM, “A” and thereby does not create a value match.



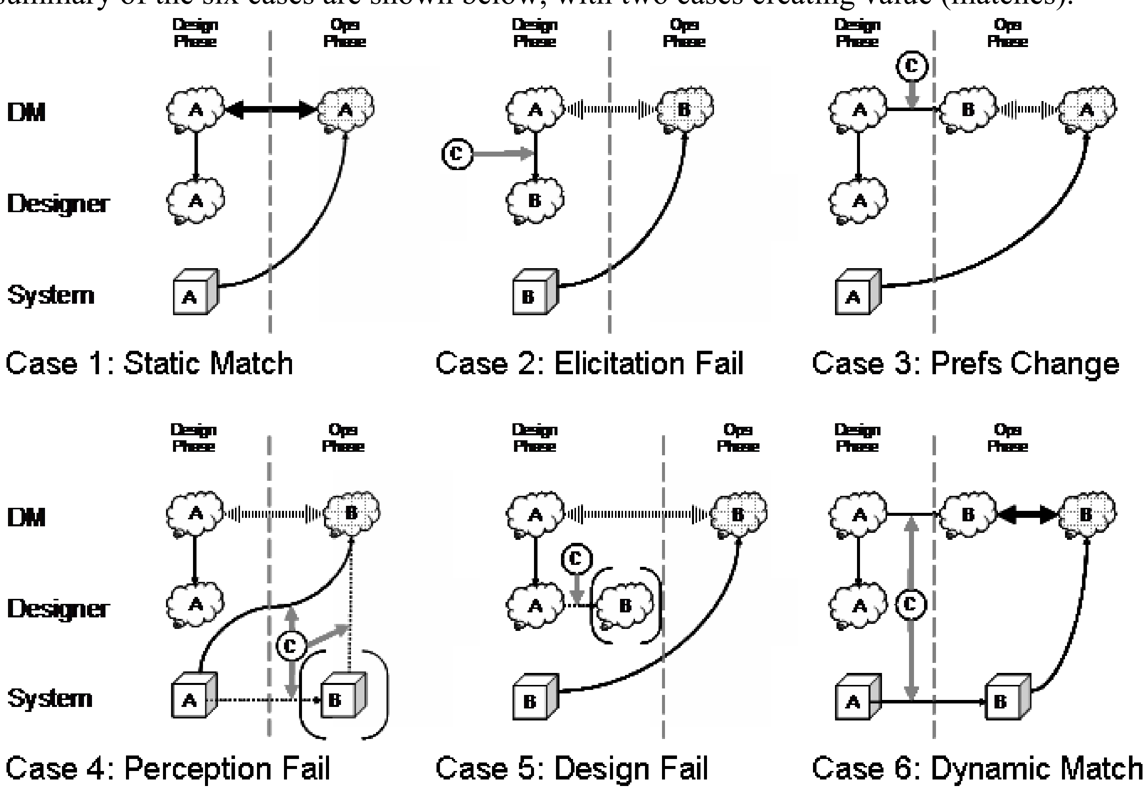
Case 6: Dynamic Match

The sixth case is one of dynamic match. The DM has preference set “A” and the Designer captures a set “A.” “Context effects” may have a role changing the DM preferences from “A” to “B” and the display of System characteristics from “A” to “B” at some point prior to or after operations begin. In operation, the System is seen to display “B,” which matches the preference set of the DM, “B” and thereby creates a value match.



Summary of Mismatch Cases

A summary of the six cases are shown below, with two cases creating value (matches).



Value Mismatch characterized through market exchange

Dynamic supply

- Time constant for introduction of new systems
    - Infrastructure
    - Demander "preferences"
    - "Context": policy, technology, concepts, resources, culture
    - Individual → group time constants

Dynamic demand

- Time constant for demand on offered systems
    - "Context": policy, technology, concepts, resources, culture
    - Prior "preferences"
    - "Drift"
    - Individual → group time constants

A level above considerations of individual choice over time is the interaction of choice between individuals in the context of a market. The basic unit of dynamic value exchange occurs at the level of an individual decision maker "demander" and an individual system "supplier." Two fundamental dynamic forces exist at this level: the changing value perception of the decision maker and the changing system offerings of the system "supplier." Mutual exchange of value occurs when both the roles of supplier and demander are fulfilled by the same individuals and organizations. For example as a consumer looking for a new computer, that "demander" has certain preference regarding the attributes of the new computer. The system "supplier" could be a computer retailer selling computer systems. That computer retailer also "demands" compensation for the system and requires that the consumer "supply" money as payment. For simplicity sake, the "supplier" for the following discussion will be the system designer, perhaps acting on behalf of a larger entity. The "demander" will be the decision maker under consideration.

A basic model of the dynamics of interaction between the supplier and demander is as follows. Suppose a demander has Prior Preferences regarding a system's traits. He knows what is good and what is bad and if given a set to choose from, would be able to order a list of alternatives from most to least appealing. Those Prior Preferences may change over time due to changes in individual taste or other forces. Suppose further that the Demander exists in a Context, which includes information and pressures that may affect how the Demander sees the world at that instant in time. The Context will vary at some possibly variable rate. According to (Baron 2000), some researchers believe that individual tastes and preferences have a Drift associated with random fluctuations in belief. Drift could be caused at the neurological scale, or subconscious level. The Demander's current preferences will be some function of Prior Preferences, the Context, and Drift. Making a choice among alternative system options, the Demander "articulates" part of that current preference.[5]

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[5] ✍📖 An interesting consideration relates to the case of the Demander with multiple personalities. Such individuals may have multiple or conflicting preferences, with the expression of "dominant" values changing over time. Congress as a single entity can be considered of this class since each individual member may have differing

Suppose there is a Supplier who generates the system offerings for the demander. The set of options offered will change as a function of three forces: the Current Preferences of the Demander, delayed effects from the Context, and Infrastructure time scales. Presuming that the system Supplier desires to have her system offerings chosen by the Demander, the system offerings will seek to match the articulated value proposition of the Demander. The Supplier may also seek to glean insights from its Context, deriving new possibilities for systems or attempting to predict possible future demands. A delay exists between the current Context and its effect on the system offerings due to the need for processing and implementation of the information. The last force affecting the offerings is the infrastructure time scale, which relates to the fundamental constraints on the system offerings, such as political inertia, manufacturing limitations, and in-house knowledge and experience. The Supplier can introduce new or changed offerings on a time scale that is a function of the three forces. An important feedback loop is created as the system offerings themselves become part of the new Context faced by both the current and future Demander and Supplier.

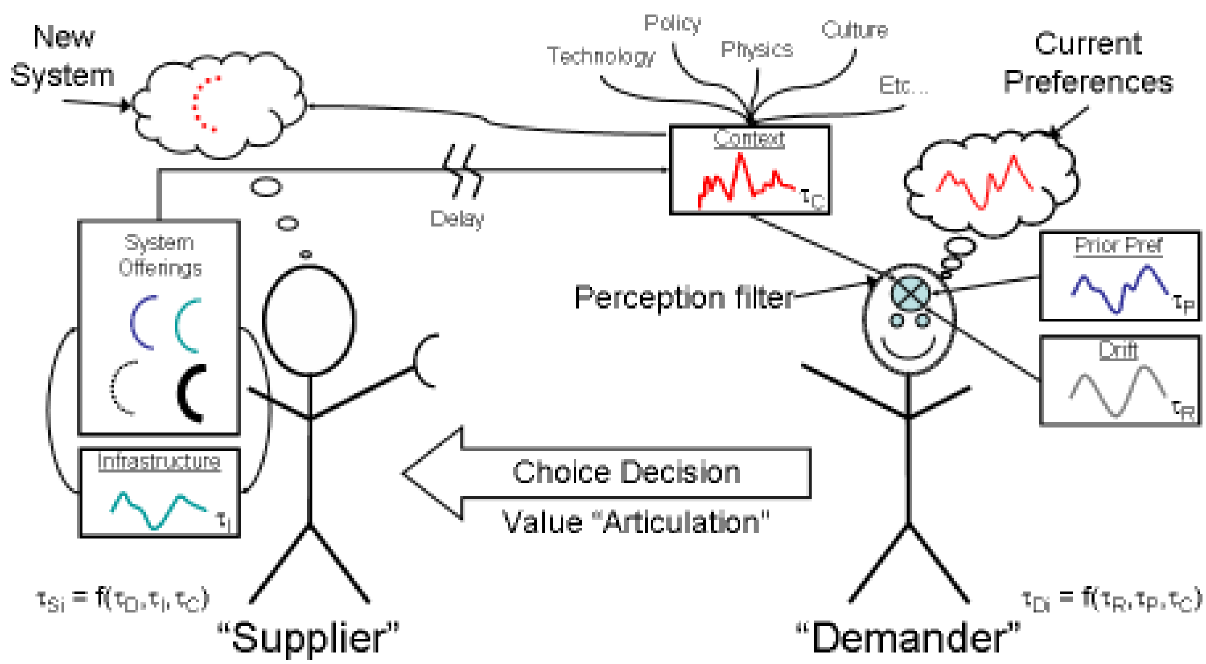

Figure 8 The roots of dynamic individual preferences

Using this relatively simple dynamic model of value transference through choice articulation, insights can be made into the interaction of various combinations and numbers of suppliers and demanders, revealing cases where value transference may be inefficient.

and conflicting preferences, yet the decisions articulated by Congress may or may not remain stable over time as "dominant" Congressmen become the voice for the body. Treatment of Congress as a multiple Demander case may provide insight into the problem as well, but reality lies somewhere in between (has single demander effects, but multiple demander preferences). Further work should be considered in this area.

Market Cases

Case 1: Many Suppliers, Many Demanders

In the first case, consider the market that is both a polyopoly (many suppliers) and a polyopsony (many demanders). In this case, the dispersion of preferences of the various demanders could "average out" since the suppliers need only meet the average demander in order to ensure choice of her offering. Additionally, the variability of the demander preferences will be smoothed out, assuming only weakly correlated preferences. The time constant of preference change for aggregated multiple demanders will be larger than that of an individual demander.

Many suppliers ensure a variety of choices, maximizing the likelihood that demanders will find offerings that deliver value. In effect, the time constant for offering set change is less than that of an individual supplier due to asynchronous individual offering change. The two time constants move towards a dynamically efficient situation, where aggregate preferences vary more slowly and aggregate new offerings vary more quickly, perhaps converging.

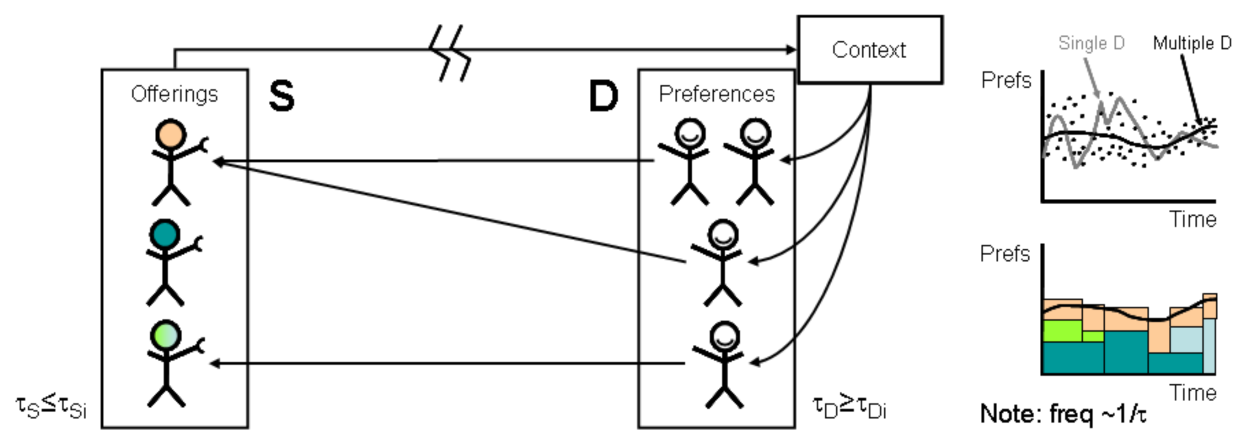

Figure 9 Market case 1: Many suppliers, many demanders

In the long run, the dispersion of preferences of demanders may collapse, resulting in preference synchronization. Such is the case when the choices of individuals affect the context as seen by future individuals, who may see prior choices as more attractive. Offerings may converge over time as well to meet the synchronized preferences. The effect is similar to reducing the number of suppliers and demanders. Perturbations introduced by the Context, however, may prevent any stable equilibrium from forming and re-disperse the demander's preferences.

This case is akin to perfect competition and is the most efficient situation for delivering value to demanders. In this case, the market determines the "price," or terms of the system offering choice. Figure 9 shows this market case one.

Case 2: Single Supplier, Many Demanders

In the second case, consider the market that is both a monopoly (single supplier) and a polyopsony (many demanders). In this case, like the first case, the aggregate preferences of the demanders are smoother than those of the individual demanders. The aggregate system offering time is slower than in case one, however, as no other supplier can introduce a new offering during the "off" time for the competitor. Fewer offerings mean more dissatisfied demanders and less value delivered.

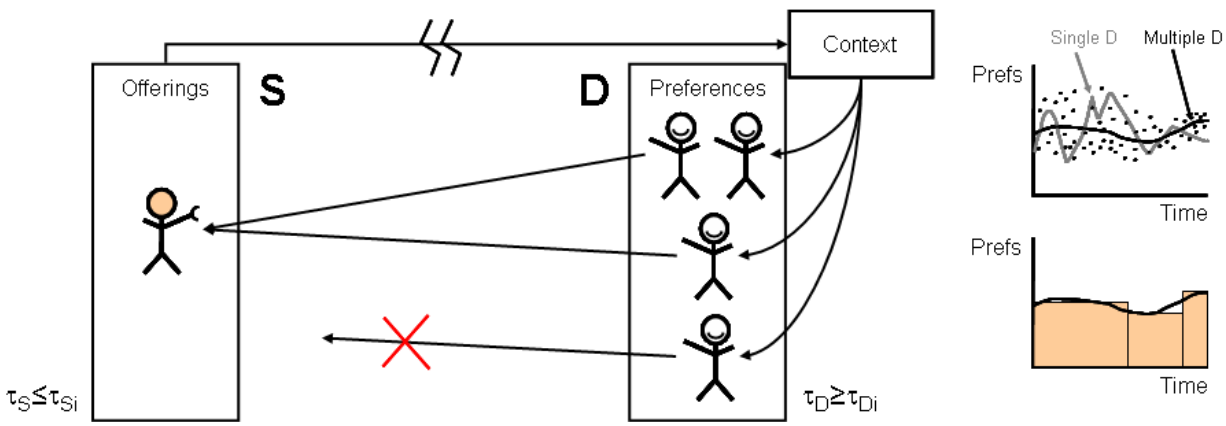

Figure 10 Market case 2: Single supplier, many demanders

In the long run, the demanders may synchronize their preferences to the offering set, or to each other. Likewise, the supplier may try to actively alter the demanders' preferences to synchronize with the offering set in order to increase net value transfer between suppliers and demanders.

This case is akin to monopoly markets and is much less efficient for delivering value to demanders, though it may deliver more value to the supplier than case one. In this case, the supplier determines the "price," or terms of the system offering choice. Figure 10 shows case two.

Case 3: Many Suppliers, Single Demander

In the third case, consider the market that is both a polyopoly (many suppliers) and a monopsony (single demander). In this case, the aggregate preferences of the demander are the same as the individual preferences, with more variability than the many demander case. In the short run, the suppliers will have many offerings and an aggregate system offering rate faster than that of a single supplier. Since the demander will most likely only choose offerings from a subset of the entire supplier set, the suppliers seek to cater to the preferences of the demander as much as possible. Competition among the suppliers for the attentions of the demander will likely result in a decrease in the number of suppliers over time.

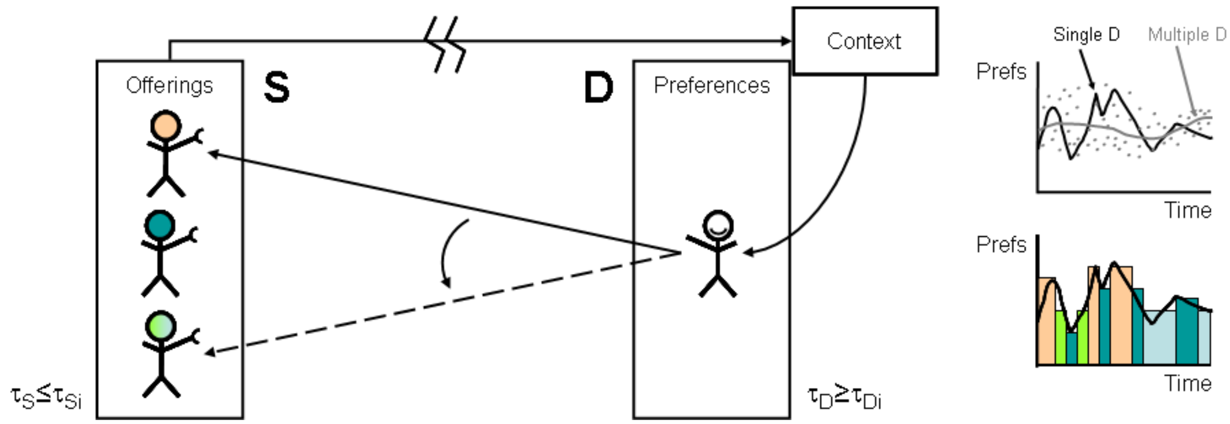

Figure 11 Market case 3: Many suppliers, single demander

In the long run, the demander will face a shrinking set of suppliers and thus an increase in the time constant for system offering set change. In the short run, the demander receives a large amount of value as the system offering set will likely meet many of the preferences and change relatively quickly to stay synchronized with any changes in the demander preferences. In the long run, however, the offerings will decrease in variety and rate of change and will likely deliver less value over time to the demander. The long run equilibrium tends toward few suppliers. Additionally, since the aggregate preferences of the demander are not averaged, the context may have a significant affect on the aggregate preferences. As such, the suppliers may seek to synchronize with the context in an attempt to anticipate the demander preferences.

The U.S. aerospace industry most likely fits this case, with at first a large number of aerospace companies vying for the attentions of the single demander (the U.S. government). Over time, the industry has seen massive consolidations down to a few suppliers that are alternatively selected by the government in order to ensure the existence of more than one supplier. The demander in this case is aware that more value may be lost if the set of suppliers further decreases.

This case is akin to monopsony markets and is much less efficient for delivering value to suppliers, though it may deliver more value to the demander than in case one. In this case, the demander determines the "price," or terms of the system offering choice. Figure 11 shows case three.

Case 4: Single Supplier, Single Demander

In the fourth case, consider the market that is both a monopoly (single supplier) and a monopsony (single demander). In this case, the aggregate preferences are the same as the individual preferences, and the aggregate system offering set is the same as that of an individual supplier. Exactly opposite to case one, the time constants diverge, where the rate of change of preferences is smaller (faster change) and the rate of change of offerings is larger (slower change) than in an aggregated market. In order to create a system to deliver value that is articulated by the demander, the supplier often assumes static preferences. If the supplier expects that the demander will not choose an offering, the supplier may be better off not supplying at all. Likewise, if the demander expects the offerings to not deliver sufficient value, the demander may attempt to create the offering on his own.

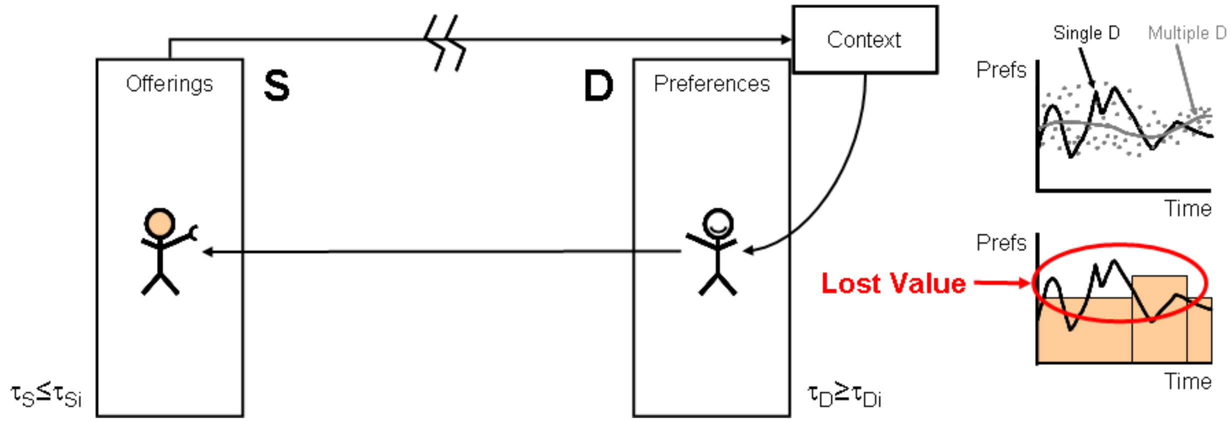

Figure 12 Market case 4: Single supplier, single demander

In the long run, strong coupling between the demander and the context may exist and the supplier may attempt to explicitly affect the context in order to increase the likelihood of continuing system demands. The modern U.S. Aerospace industry closely approaches this case, with the demander as the U.S. government. The government sometimes builds its own systems (JPL), and sometimes contracts out. Likewise, the sheer size of the Aerospace industrial job base, as well as direct lobbying of Congress, alters the context making continued government patronage more attractive than not.

This case is akin to single exchange interactions and has the most variation in efficiently delivering value to both supplier and demander. If the system offerings diverge from demander preferences, large value gaps will exist. In this case, negotiation determines the "price," or terms of the system offering choice. Figure 12 shows case four.

Market Cases Discussion

Of the four cases of value interaction discussed, case four poses the largest opportunity for value delivery improvement.[6] The case described the interaction of a single supplier and demander, which closely approximates the case of system design for a decision maker. The goal should be to deliver maximum value to both the supplier and demander by matching the time constant for system offering change to the time constant of demander preference change. Figure 13 illustrates the differences between the cases, and highlights the largest value gap exists for case four.

[6] ✍📖 An opportunity exists for applying the four market frameworks presented here to the U.S. Aerospace industry. An historical study analyzing the consolidation of the industry may provide insights into the forces at play in such a market model. Intervention at the market level could be proposed based on the model and desired system offerings and preferences sets.

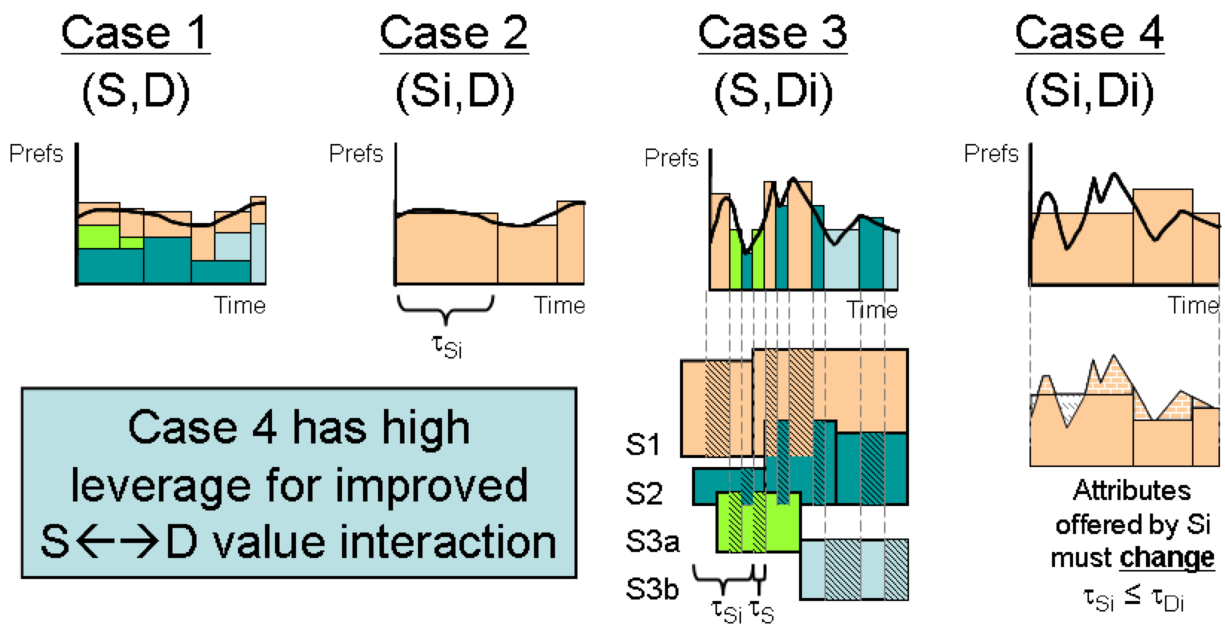

Figure 13 Value matching comparison for market cases

In the MATE context, the attributes of the system offered by the supplier must change with a time constant less than or equal to that of the changing preferences of the demander. The system and its designer must embrace dynamicism in order to fill the value gap.

Discussions

- Usefulness of concept to types of systems/products/services
  - Interpretation of four market cases
- Implication for "designers"
  - motivation of changeability
  - relaxation of static assumptions
  - pressures towards mass customization

Conclusions

The objective of this research is to characterize cases of value mismatch caused by differences between system design characteristics and decision maker expectations and to develop a mitigation strategy through extension of Design for Changeability using Dynamic Multi-Attribute Tradespace Exploration (Dynamic MATE). Dynamic MATE is a design approach to account for changeability and unarticulated value. While introduced as a dynamic value creating design response to changing value perceptions, more research needs to be done to properly characterize when, how, and why value perceptions change and more importantly, when, how, and why systems appear to fail to deliver value to stakeholders.

Developing robust systems has traditionally focused on maintaining system functionality over a range of operating conditions. The goal of system design however, is not robust systems per se, but rather the delivery of value to system stakeholders. Dealing with value mismatch, including perception changes, has not been dealt with in the same manner as classical notions of robustness. It is inevitable that decision makers change their mind, and therefore their perception of value of a system. In order to maintain value delivery over a system lifecycle, a system must change to match new decision maker preferences. If system designers could anticipate or account for changing preferences when designing products or services, they would be empowered to create more valuable systems over time. As such, good designs should not be the sole province of the rare star system designers with decades of experience, but rather the product of proper training in the fundamentals of system design. A holistic, foundationally strong system design methodology will streamline the teaching of advanced system design concepts and empower the next generation of design engineer. These designers will be able to identify, anticipate, and respond to cases of value mismatch, thereby mitigating potential for lost value and increasing overall system lifecycle value delivery.

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