A Role for Interactive Tradespace Exploration in Multi-Stakeholder Negotiations

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Track 25-SSEE-3: Economic Considerations for Space Arch.
AIAA Space 2010

Outline

- Multi-Stakeholder Design Negotiations
- Tradespace Exploration (TSE)
  - Prior negotiation-related work
  - “Tools” for interactive TSE
- Role-playing Session
- Discussion

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Multi-Stakeholder Design Negotiation

- Framing constraint ("social welfare"): No "reasonable" stakeholder aggregation function possible to determine "optimal" designs for multi-stakeholder problem (Arrow 1963)
- Cooperative nature of design, special case for negotiation
- Approaches for design negotiation
  - Game theory
  - Agent-based methods
- Dilemmas faced by current approaches
  - An individual has a multi-dimensional preference (utility function)
  - Assessing others' utility functions (e.g., during negotiation) is difficult
  - Contexts may vary over time
  - Discovering Pareto optimal solutions is difficult (especially in real time)
- Pitfalls of aggregating preferences in advance
  - May exclude "win-win" solutions before proper consideration
  - Alternative set may still be in flux and superior solutions may not be considered if compromise made "too early"

Negotiation should allow for consideration of: own preferences, others' preferences, set of alternatives, and changes in all of these

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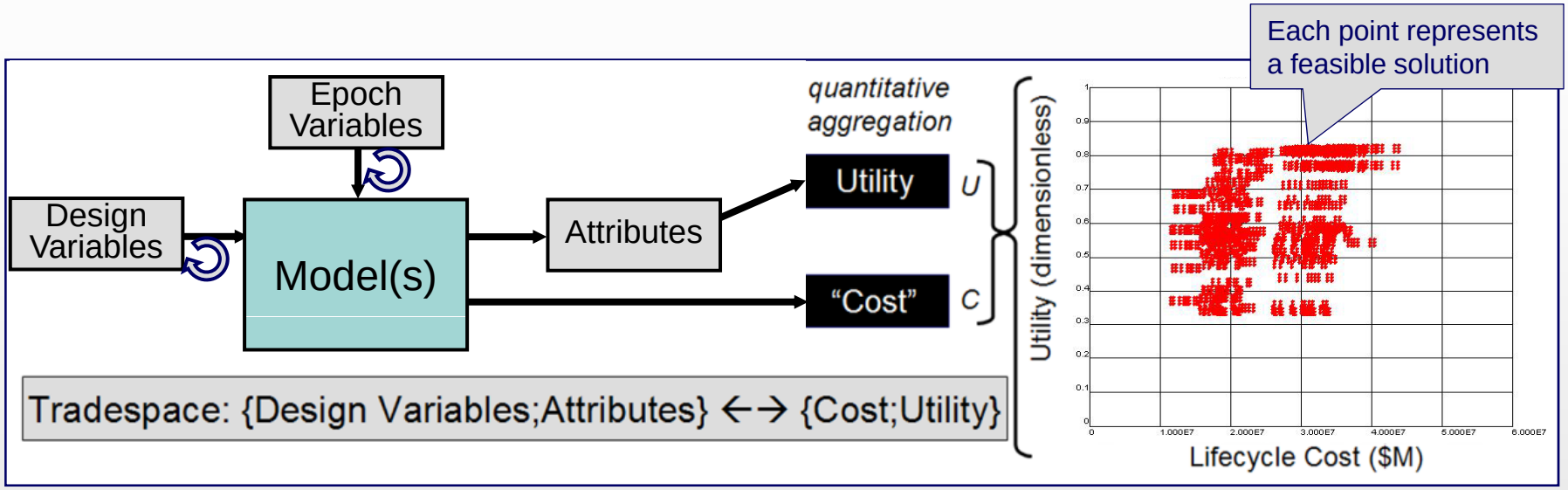
Design Tradespace Evaluation



Compares system designs on a common, quantitative basis

- Uses computer-based models to compare thousands of designs
- Avoids limits of local point solutions
- Maps structure of stakeholder value onto design space
- Simulation can be used to account for design uncertainties (i.e., cost, schedule, performance uncertainty bubbles)

Design tradespaces provide high-level insights into system-level trade-offs.

Source: Ross, A.M., McManus, H.L., Rhodes, D.H., Hastings, D.E., and Long, A.M., "Responsive Systems Comparison Method: Dynamic Insights into Designing a Satellite Radar System," AIAA Space 2009, Pasadena, CA, September 2009.

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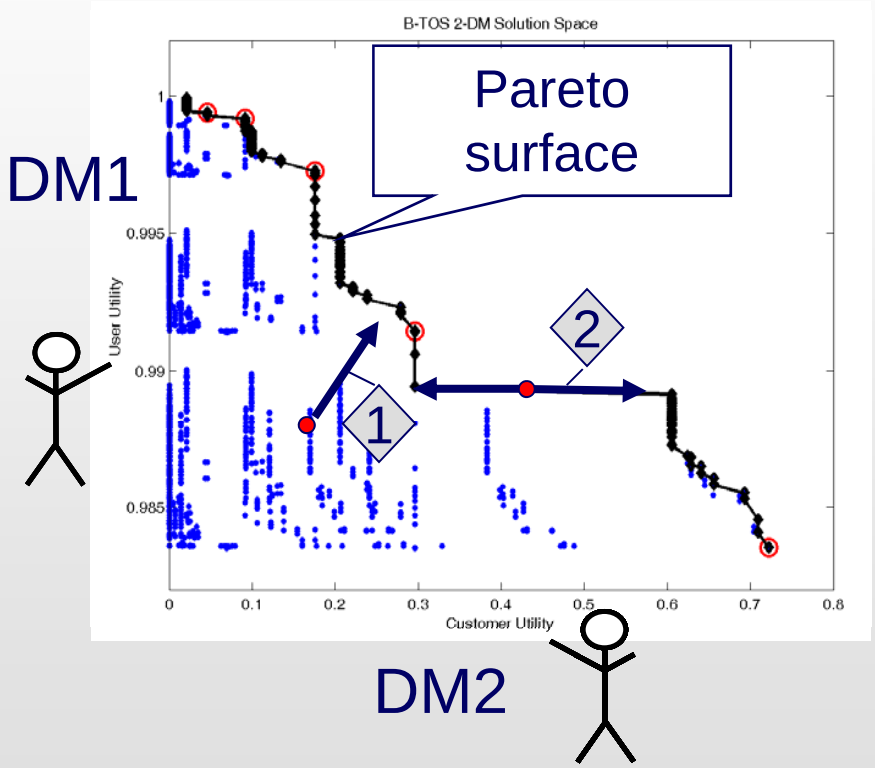
Multi-DM Tradespace Negotiation

Multiple Decision Maker Tradespace



- In general, no optimum solution to problem with multiple stakeholders having conflicting needs (See Arrow's General Possibility Theorem, 1963)
- Tradespace aids negotiation
  - ① Finding the win-win changes (moving toward Pareto front)
  - ② Finding the real trades (along the Pareto front)

Prior work proposes two approaches to finding compromise solutions: mathematically-based (Pareto surfaces), and negotiation-based (humans)

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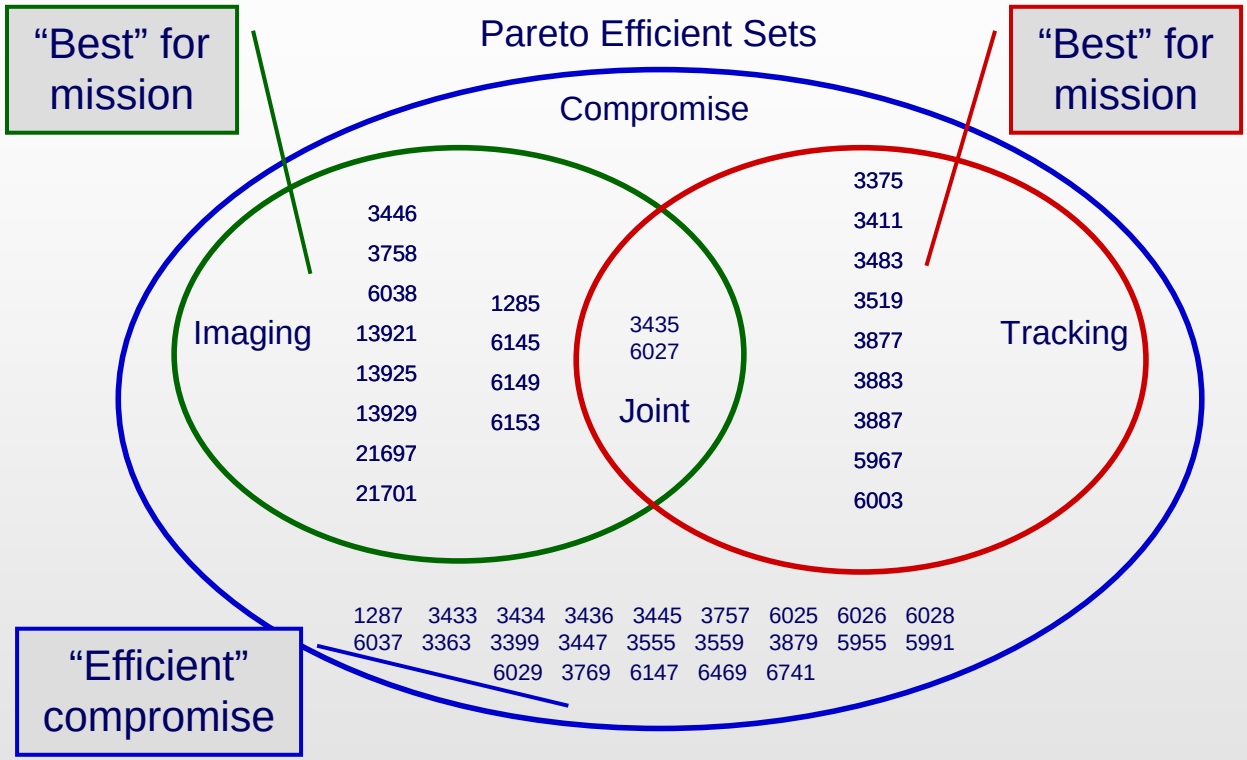
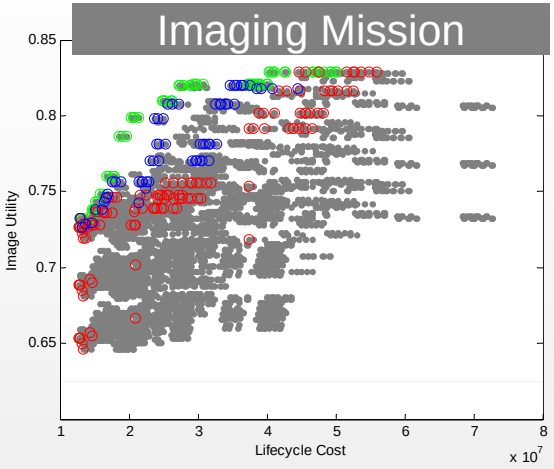
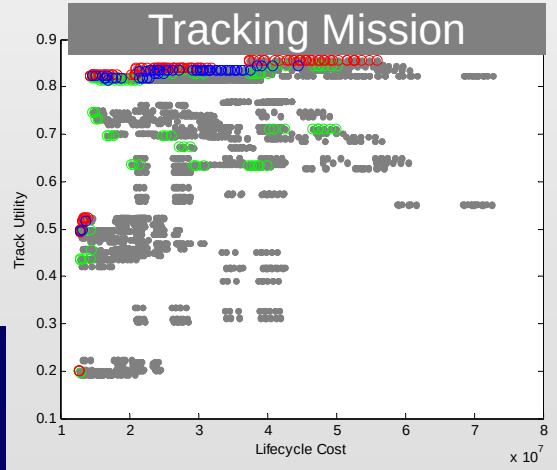
Mathematically-based "Compromises" across Missions and Stakeholders







Hypothesis: Method provides quantitative approach for discovering "best" mission-specific designs, as well as "efficient" (benefit at cost) compromises across missions and stakeholders

Source: Ross, A.M., McManus, H.L., Rhodes, D.H., Hastings, D.E., and Long, A.M., "Responsive Systems Comparison Method: Dynamic Insights into Designing a Satellite Radar System," AIAA Space 2009, Pasadena, CA, September 2009.

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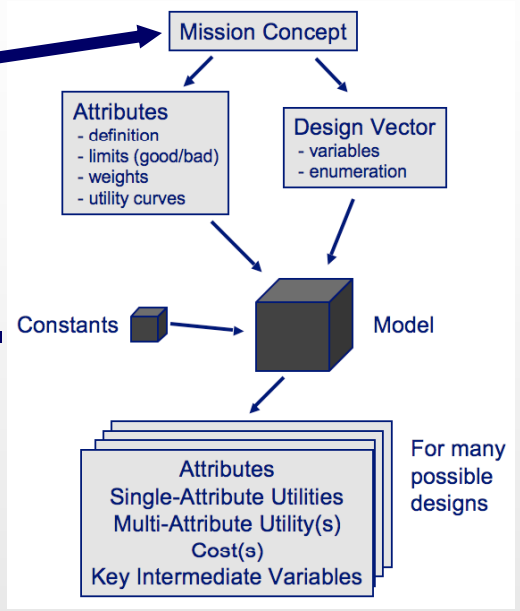
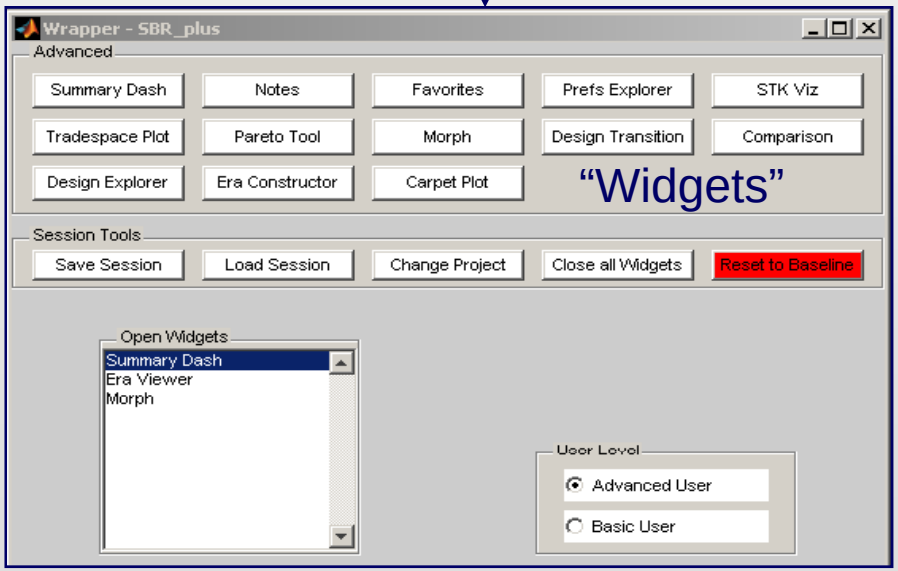
Toward Negotiation-based Compromises: VisLab 1.0

Select project

- Satellite Radar System
- Space Tug
- other



Database



- VisLab 1.0 is internally developed software for performing interactive tradespace exploration
- Alternative interactive TSE software may enable similar results (e.g., using Excel)

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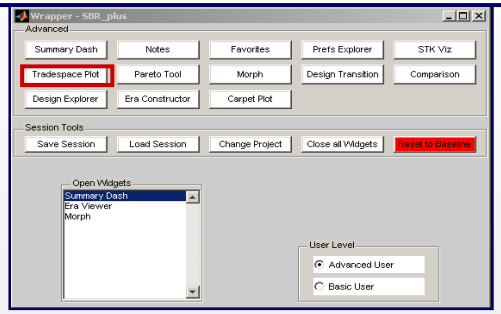
Tradespace Plot

The Tradespace widget generates a scatter plot from DB for a given epoch



Features

- Multiple tradespace widgets can be open at the same time to allow side-by-side comparisons
- Plots updated in real time by changes made in other widgets

"Click on point" capability

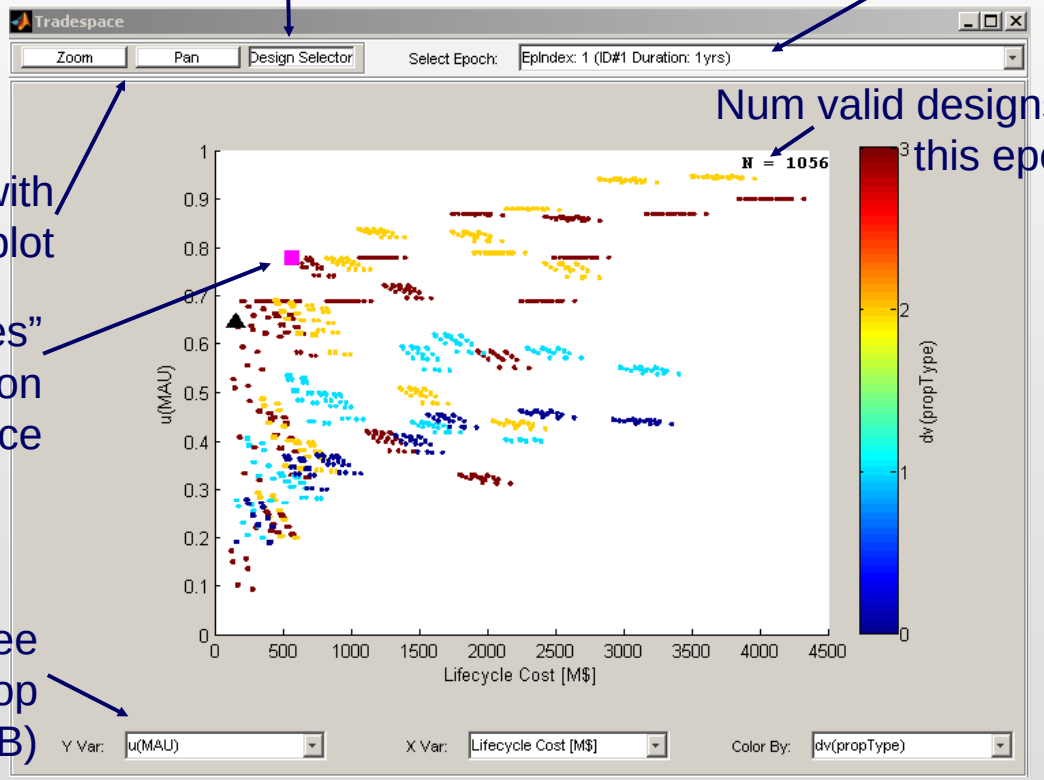
Select current epoch (from Era or other)

Num valid designs in this epoch

Interact with plot

"Favorites" plotted on tradespace

Plot three dimensions (drop downs from DB)



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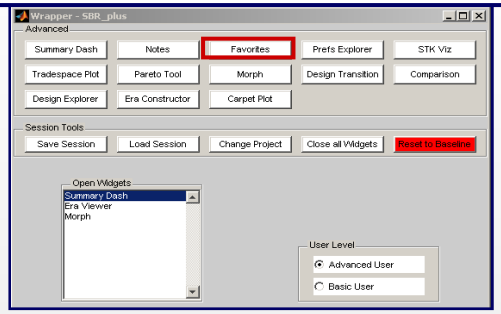
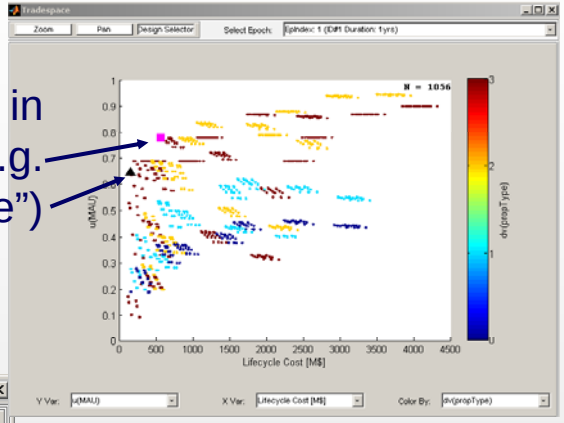
Favorites

The Favorites widget allows a set of designs to be tracked and formatted across widgets



Favorites plotted in other widgets (e.g. "tradespace")

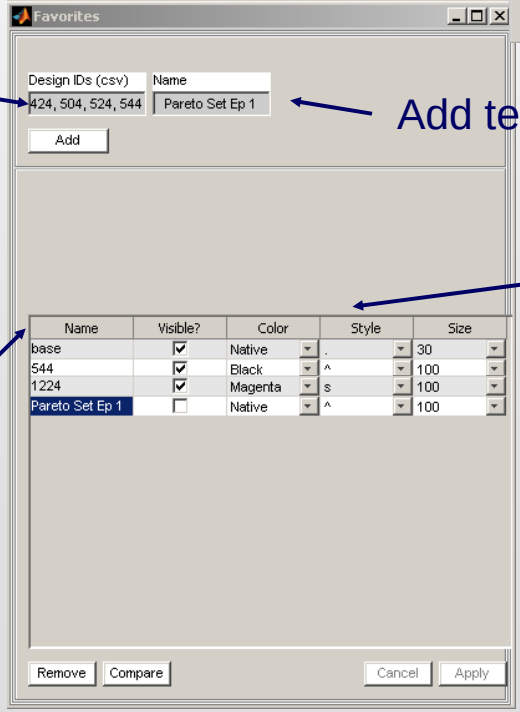


Features

- Single or multiple designs can be grouped as a favorite
- Each favorite can be consistently displayed and formatted across widgets

Enter design ID(s)

Add text label



Specify plot formatting for each favorite

List of all favorites

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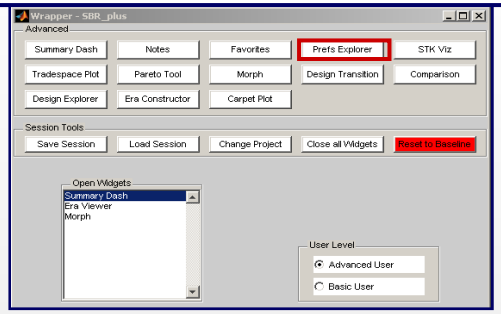
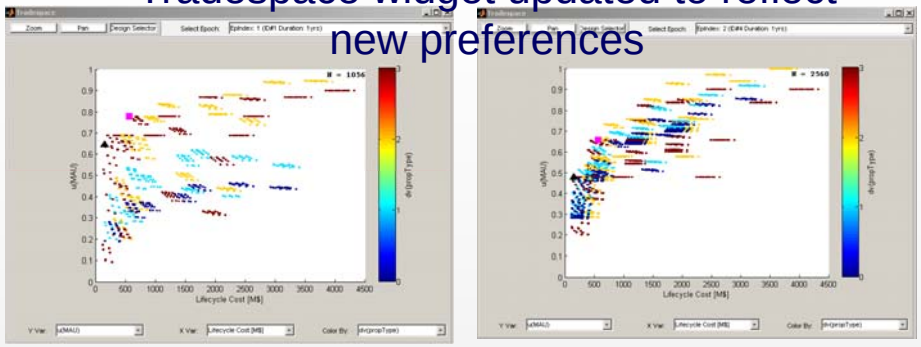
Preferences Explorer

The Preferences widget displays and allows alteration of a decision maker's preferences



Tradespace widget updated to reflect new preferences



Features

- Preferences can be displayed and edited
- Local mode allows local "playing"; global mode propagates to other widgets
- Favorites can be displayed

Select attribute

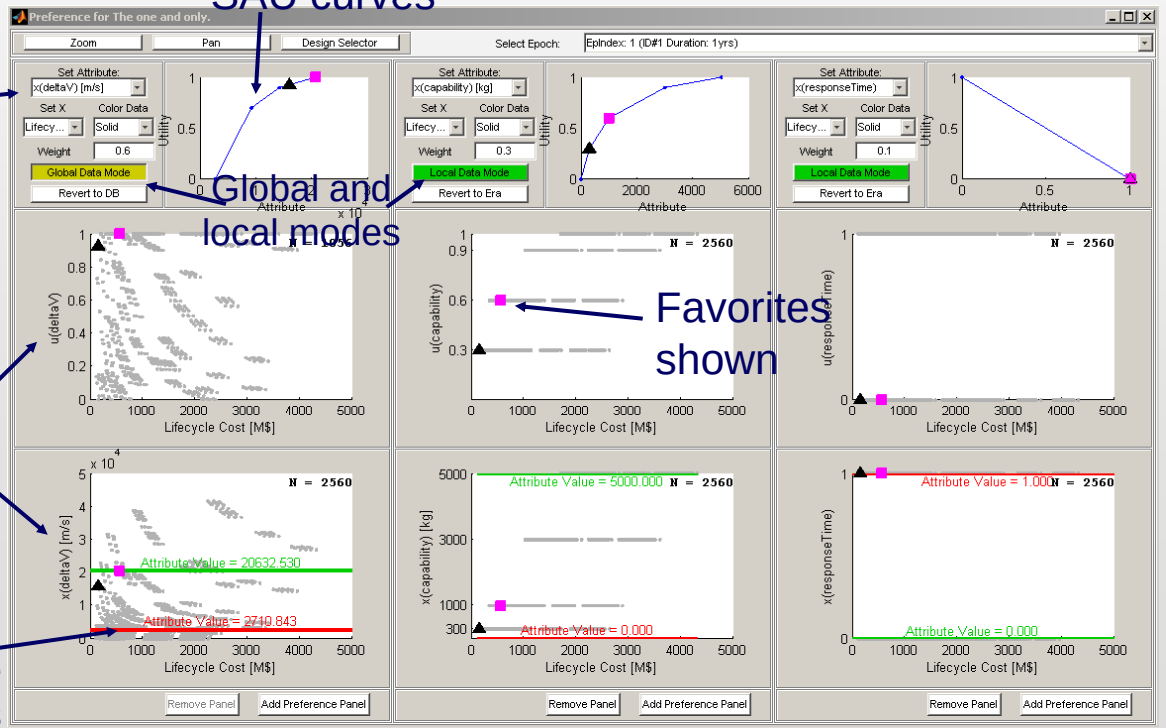
SAU curves

Global and local modes

Shows tradespace with SAUs attribute values

Favorites shown

Bars show min acceptable, max desirable attribute levels



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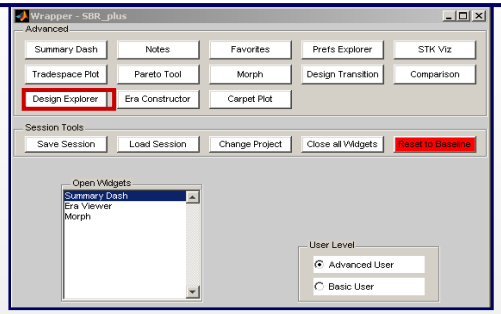
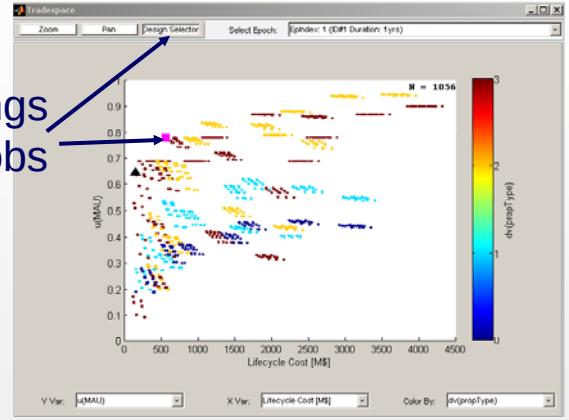
Design Explorer

The Design Explorer widget allows (a) design(s) to be specified or looked up from DB



"Click on point" brings up design knobs



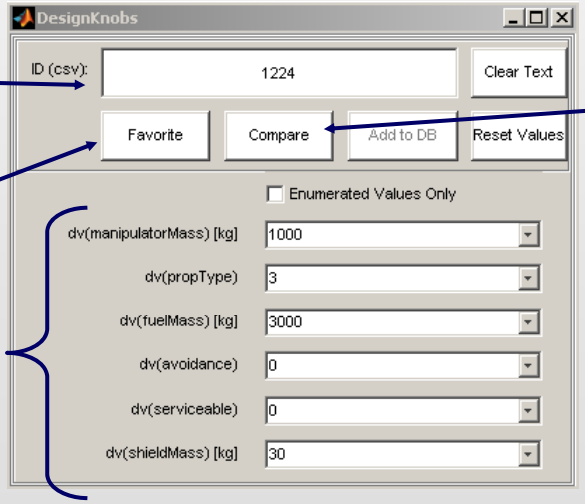
Features

- Single or multiple designs can be specified if entered as ID(s)
- Single or multiple designs can be looked up if entered as dv values
- Linked to "design selector" in tradespace widget

Enter design ID(s) (or look up ID(s)

Set favorite

Specify design, or have design described



Send to comparison tool

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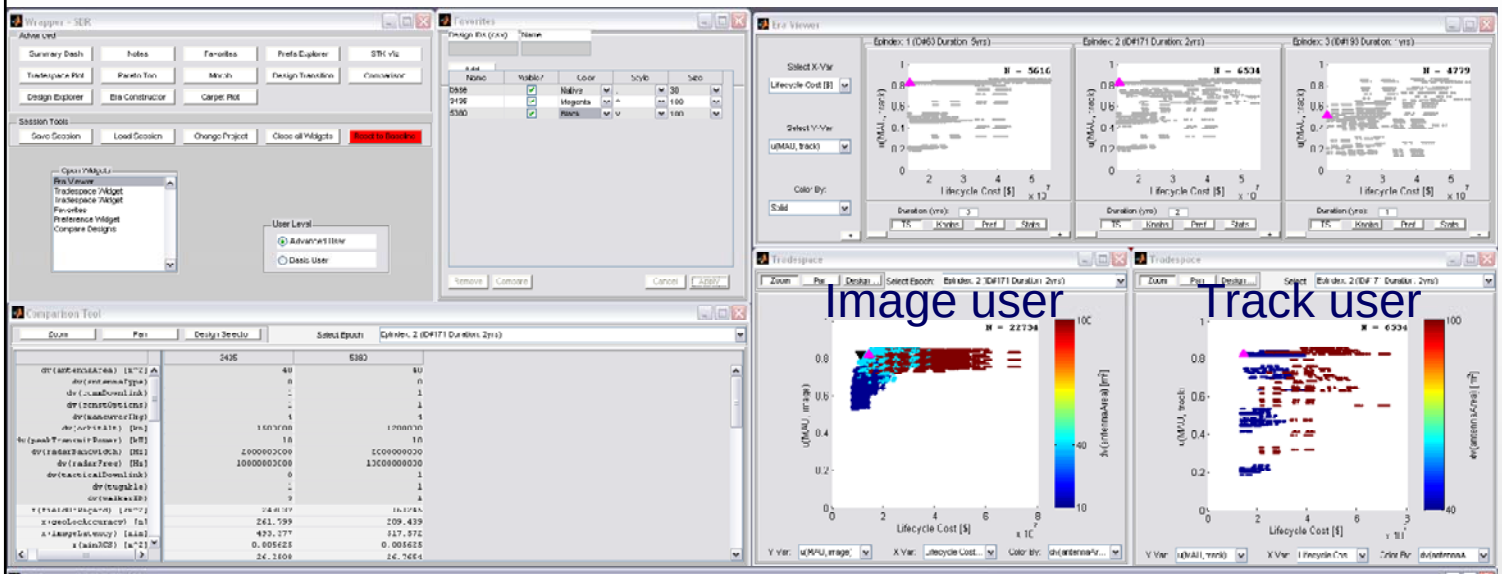
Early Emergent Insights



Key

- Design 3435
- Design 5380

Design 3435 is good for track user, but only okay for image user.

Design 5380 is better for image user.

Where is design 5380 on track user tradespace?

Find offending constraint

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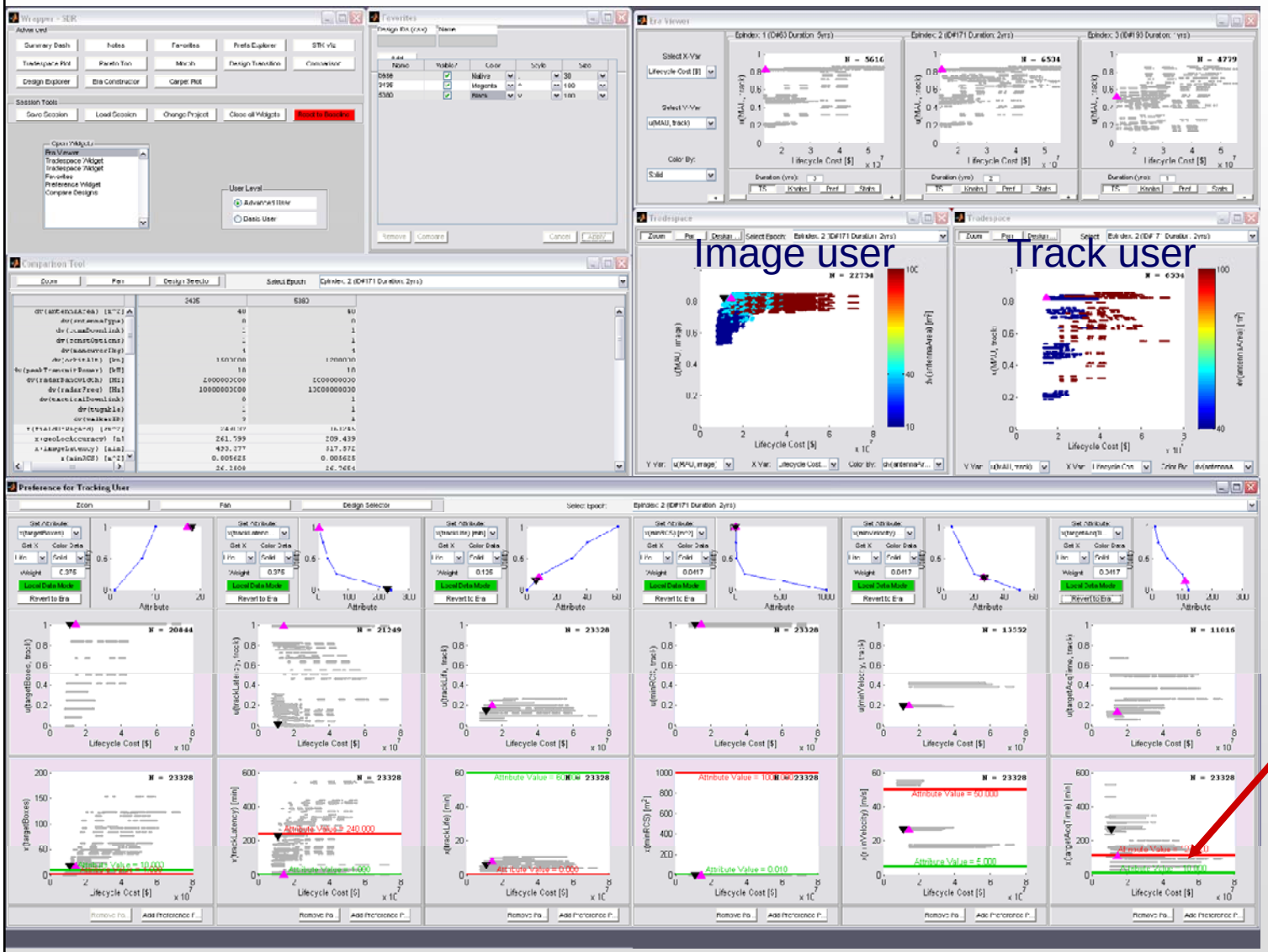
Early Emergent Insights



Key

- Design 3435
- Design 5380

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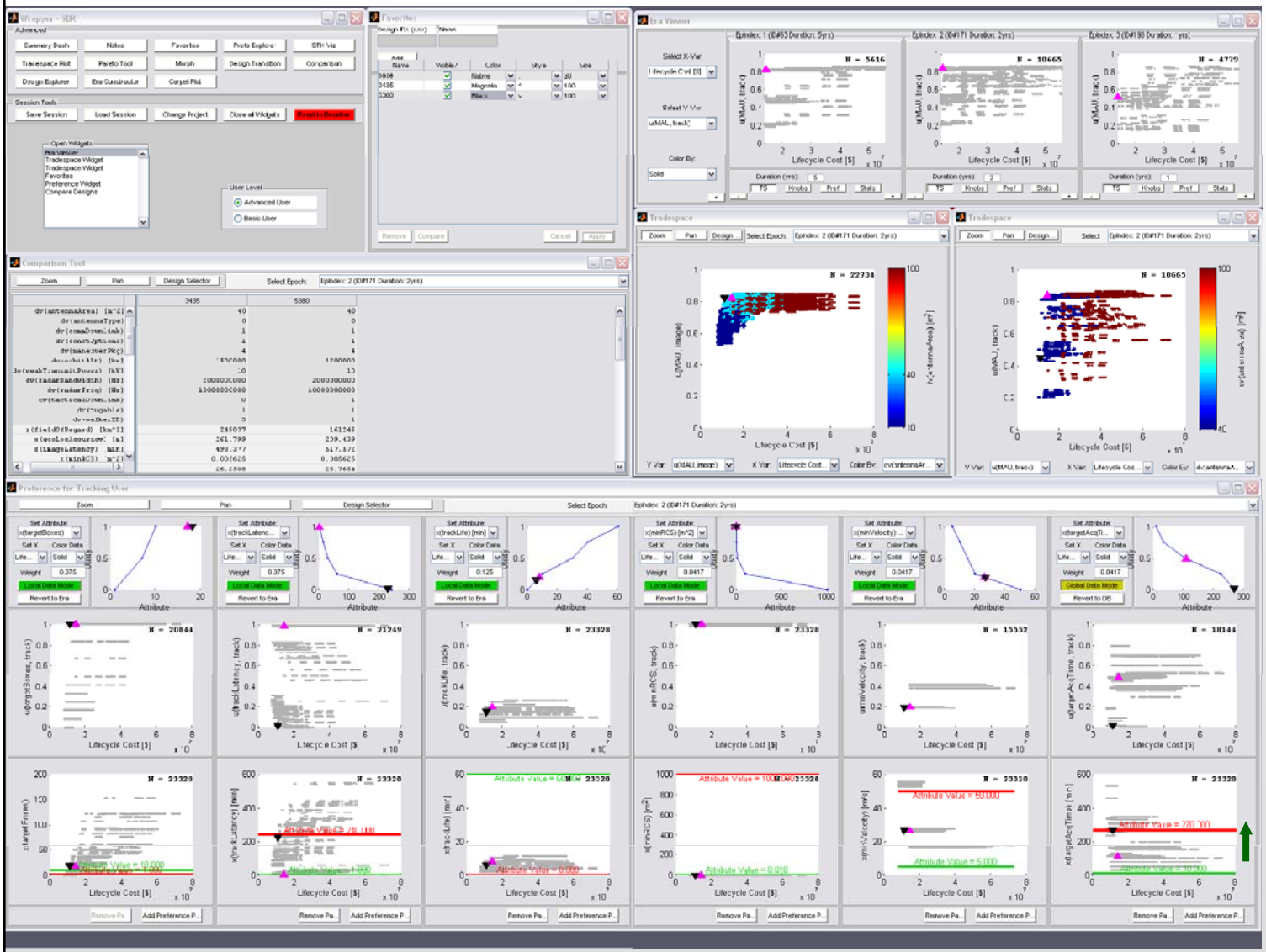
Changing Preferences in Real Time



Key

- Design 3435
- Design 5380

Find offending constraint

Relax offending constraint

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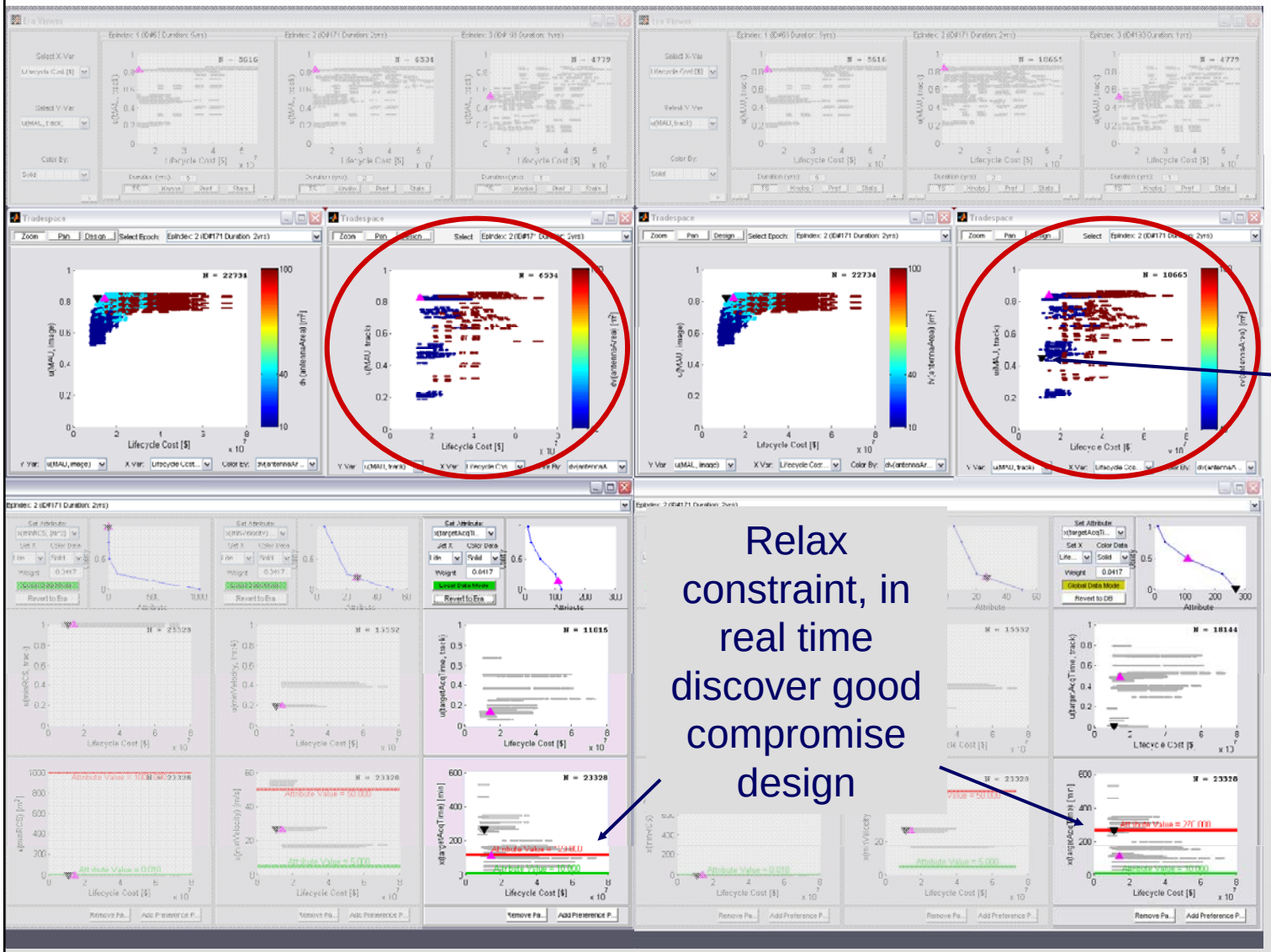
Discovering Compromises



Key

- Design 3435
- Design 5380

Design is now valid

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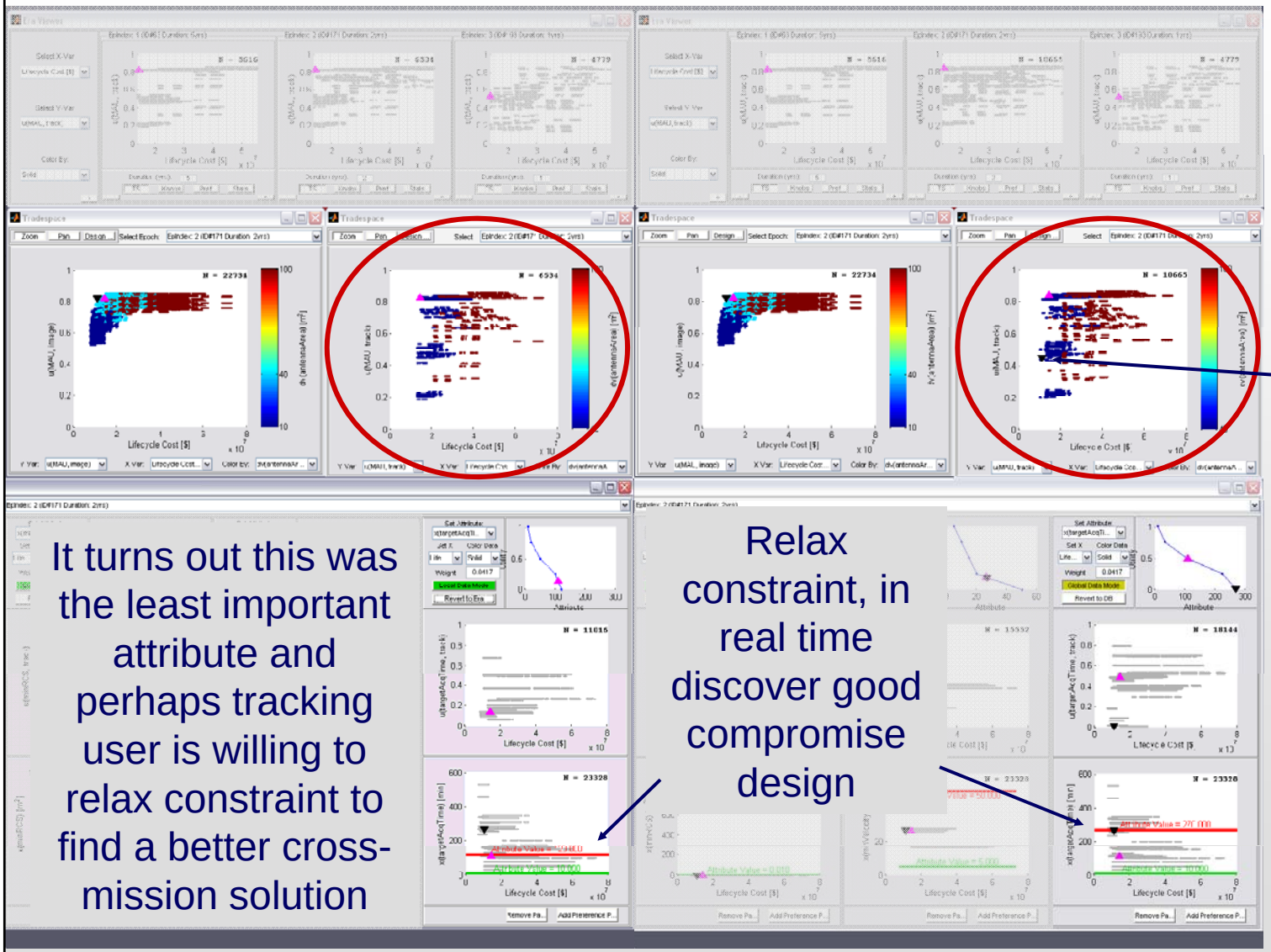
Discovering Compromises



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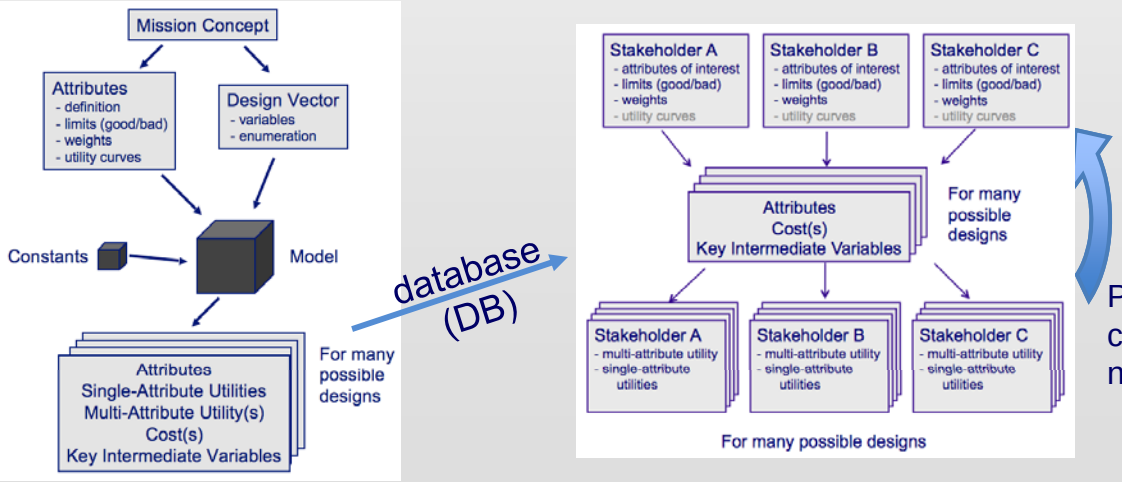
Role-Playing Session

Motivation: Wanted to test proposed methods using decision makers, not analysts

- Decision makers filled out preferences in advance using a provided worksheet that constrained preferences to derive from existing model data set
- 2 hour role-playing session using VisLab 1.0 with the following tasks:
  - Find “best” designs per mission
  - Seek “compromise” solutions across missions
  - Vary mission priorities (weights) and repeat
  - Vary mission acceptance ranges (time permitting)
  - Vary mission contexts (time, capability permitting)

Hypothesis: real-time database interaction with multiple simultaneous decision makers will allow for feedback between preference updating and “favorite” solutions, allowing for better compromises



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Role-playing Scenarios

- Interactive tradespace exploration can be used for many applications (e.g. multi-stakeholder negotiation, multi-level design evaluation, system evolution path planning, etc.)
- In this case, a negotiation application was proposed
- Two case studies: X-TOS and SRS
  - For X-TOS, please see paper
  - For SRS
    - Three mission decision makers (e.g., Imaging Mission, Tracking Mission, etc.)
    - Potential attributes constrained by prior modeling effort

Preferences to be elicited from DMs:
Acceptability range for each attribute
Weighting for each attribute

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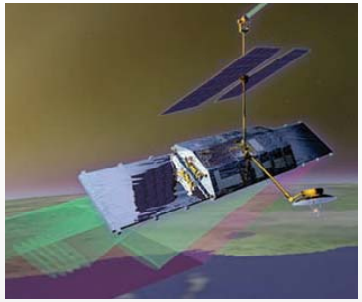
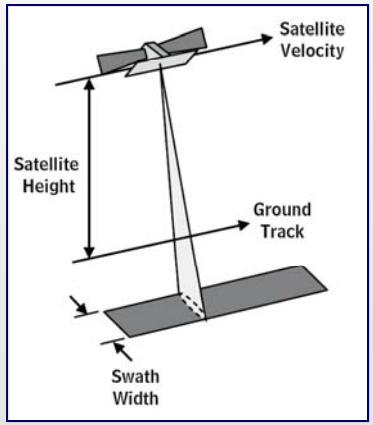
Case Application: Satellite Radar System (SRS)

For research purposes, a test case* was selected with requisite complexity…

Critical issue in national security space
- Unique all-weather surveillance capability
- Opportunity for impact given ongoing studies
- Rich multi-dimensional tradespace

Unit-of-analysis: SR architecture
- Radar payload
- Constellation of satellites
- Communications network





(CBO 2007)

Satellite Radar System (SRS) Value Proposition:

24 hour, all weather on-demand "Visibility and Tracking" over things that can be observed

Case Application Goal:

*To assess potential **satellite radar** system architectures for providing the United States Military a global, all-weather, on-demand capability to **image static, and track moving, ground targets**; supporting tactical military operations; and maximizing cost-effectiveness across many possible futures*

*models were "good enough" for method research, not system-specific design or acquisition recommendations

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Case Study Attributes

Provided instructions:

1. Check if part of your set
2. Enter range (min acceptable, max desirable)
3. Enter "weight"

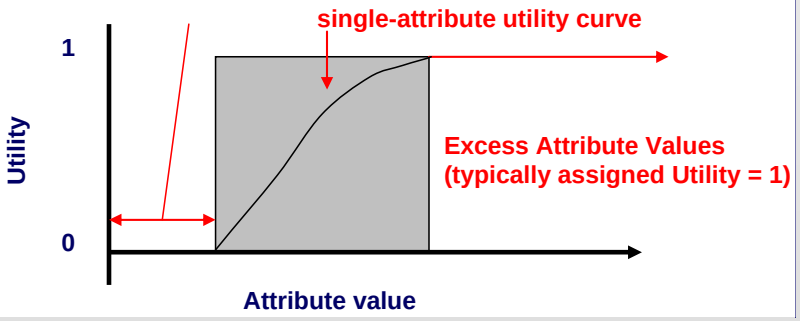
Part of set?		Attribute	units	U=0	U=1	k
Original Tracking Mission		Number of Target Boxes	#	1	10	0.375
		Tracking Latency	min	240	1	0.375
		Target Track Life	min	0	60	0.125
		Minimum Radar Cross Section	m^2	1,000	0.01	0.05
		Minimum Discernable Velocity	m/s	50	5	0.05
		Target Acquisition Time	min	120	10	0.05
Original Imaging Mission		Resolution	m	5	0.01	0.375
		Targets per Pass	#	1	10000	0.375
		Field of Regard	km^2	1,000	1,000,000	0.125
		Geo-Location Accuracy	m	500	50	0.05
		Imaging Latency	min	720	60	0.05
		Revisit Interval	min	500	50	0.05

	Attribute Name	units	Range (U=0 to U=1)
Tracking	Number of Target Boxes	#	1 - - > 10
	Tracking Latency	min	240 - - > 1
	Target Track Life	min	0 - - > 60
	Minimum Target RCS	m^2	1000 - - > 0.01
	Minimum Detectable Velocity	m/s	50 - - > 5
	Target Acquisition Time	min	120 - - > 10
Imaging	Resolution	m	5 - - > 0.01
	Targets per Pass	#	1 - - > 10,000
	Field of Regard	km^2	1,000 - - > 1,000,000
	Geo-Location Accuracy	m	500 - - > 50
	Imaging Latency	min	720 - - > 60
	Revisit Interval	min	500 - - > 50

Handout provided for operational "definitions" for these attributes

Each attribute has:

- definition (units)
- acceptable range
- weight



The "weight" for a given attribute is the overall level of satisfaction you would experience if that attribute were at its "best" level and all other attributes were at their "worst" level

Decision makers specified their attributes, ranges, and weights

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Preferences for Role-playing Session

DM "E"

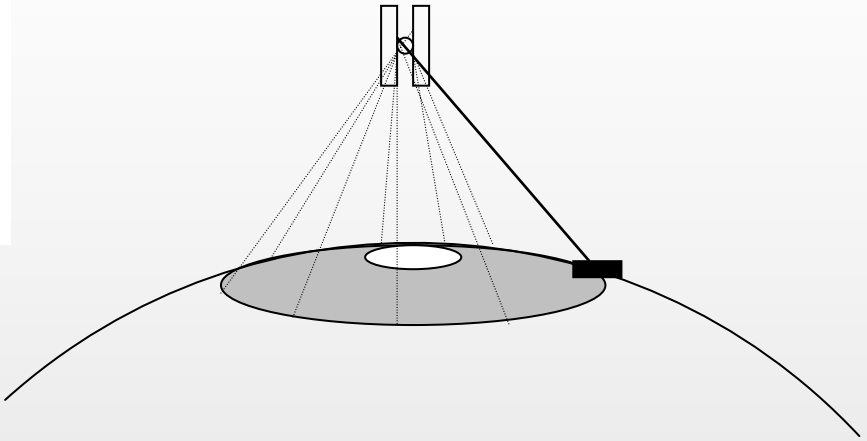
Attribute Definition	Worst	Best	Weight
Revisit Interval (min) = average time between observations on the same target	500	30	0.50
Targets Per Pass = number of targets of a given size that can be detected per pass	1	100000	0.35
Image Latency (min) = time from target view to user receipt of analyzed image data	720	60	0.15

DM "N"

Attribute Definition	Worst	Best	Weight
Geo-Location Accuracy (m) = error in absolute position of target on the ground. Assumes no references	100	3	0.50
Target Acquisition Time (min) = 95% worst case time to acquire target	120	10	0.30
Tracking Latency (min) = time from target view to user receipt of data	10	1	0.30
Minimum RCS (m2) = Theoretical minimum RCS necessary for target to be distinguished	1000	0.01	0.10
Minimum Detect. Velocity (m/s) = Theoretical minimum velocity necessary for moving target to be detected	50	5	0.10

DM "R"

Attribute Definition	Worst	Best	Weight
Image Resolution (m) = theoretical minimum separation to distinguish different targets.	5	0.01	0.45
Number of Target Boxes = number of $(200km)^2$ boxes scanned at required resolution in one pass	1	10	0.35
Revisit Interval (min) = average time between observations on the same target	500	50	0.20



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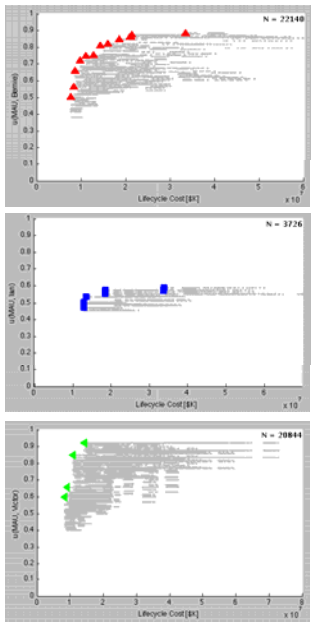
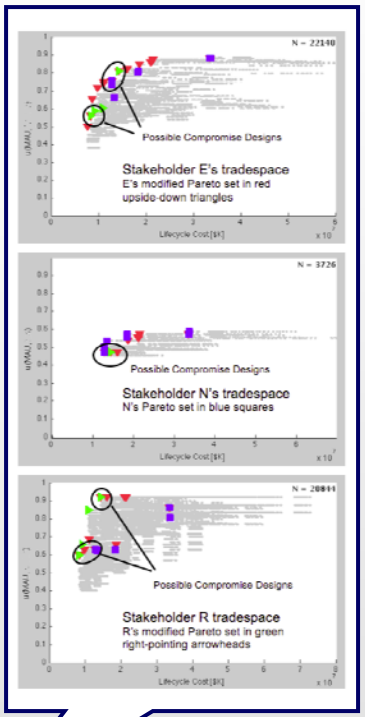
Initial Best Alternatives



Initial "favored designs"

Stake-holder	Design ID	Design Variables: Altitude (km)	Num. Sats	Ant. Area (m^2)	Bandwidth (GHz)	Power (kw)	Tac Comm	"E" MAU	"N" MAU	"R" MAU	Cost B$
E	3328	1500	10	10	2	10	no	**0.72**	X	0.62	9.6
	3436	1500	10	40	2	10	no	**0.81**	X	0.92	14.2
	3760	1500	20	40	2	10	no	**0.86**	X	0.92	20.8
N	471	800	10	40	1	1.5	yes	0.66	**0.53**	0.58	13.3
	3387	1500	10	40	1	1.5	yes	0.75	**0.47**	0.58	12.8
	6303	1200	20	40	1	1.5	yes	0.81	**0.57**	0.58	18.4
R	*424	800	10	10	2	20	no	0.56	X	**0.78**	12.0
	2692	1500	5	10	2	20	no	0.59	X	**0.66**	9.1
	*2752	1500	5	40	1	10	no	0.60	X	**0.80**	10.8
	2788	1500	5	40	2	10	no	0.60	X	**0.85**	10.8
	3436	1500	10	40	2	10	no	0.81	X	**0.92**	14.2

- Revealed design needs
  - N needs "Tac Comm"
  - R needs high bandwidth
- Under agreement, adjusted constraints to add these design choices to set of designs
- Compromises appear below and to right



Easy (but costly) compromises

Stake-holder	Design ID	Design Variables: Altitude (km)	Num. Sats	Ant. Area (m^2)	Bandwidth (GHz)	Power (kw)	Tac Comm	"E" MAU	"N" MAU	"R" MAU	Cost B$
All	3423	1500	10	40	2	1.5	yes	**0.75**	**0.47**	0.63	12.8
	3435	1500	10	40	2	10	yes	**0.81**	0.47	**0.92**	14.3
	*6027	1200	10	40	2	10	yes	**0.80**	0.50	**0.92**	14.6
	*519	800	10	40	2	10	yes	0.68	**0.53**	0.88	15.8
	**6349	1500	20	40	2	10	yes	**0.87**	**0.57**	**0.92**	22.3
E+R	2679	1500	5	10	2	10	yes	**0.56**	X	**0.60**	8.3
	2787	1500	5	40	2	10	yes	0.60	X	**0.85**	10.9

Less expensive alternatives (not for N)

no star – arrived at by design feature compromise
* selected from analytically identified multi-stakeholder Pareto set
** gold-plate design, Pareto for everyone at high cost

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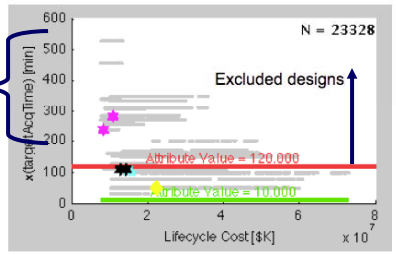
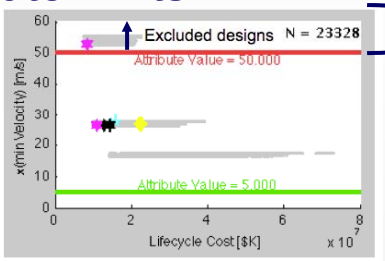
Results of Negotiation

N's attribute limits

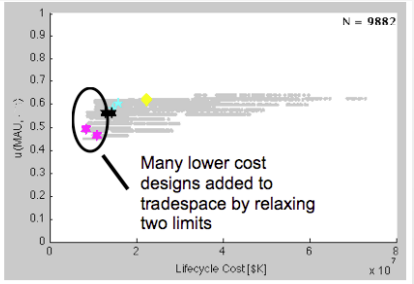
N's *target acquisition time* attribute range excludes lower cost alternatives from compromise set





N's *target min detectable velocity* attribute range excludes lower cost alternatives from compromise set

Relaxing one attribute range allows for lower cost alternatives



Relaxing both attribute ranges allows for even more lower cost alternatives

Relaxing these limits is not trivial and requires negotiation among DMs, especially since *TAT* was important to N

Negotiated compromises

Symbol	Design ID	Design Variables: Altitude (km)	Num. Sats	Ant. Area (m^2)	Bandwidth (GHz)	Power (kw)	Tac Comm	"E" MAU	"N" MAU	"R" MAU	Cost B$
Black	3423	1500	10	40	2	1.5	yes	**0.75**	0.56	0.63	12.8
Star	3435	1500	10	40	2	10	yes	**0.81**	0.56	**0.92**	14.3
Blue 5pt	6027	1200	10	40	2	10	yes	**0.80**	0.58	**0.92**	14.6
star	519	800	10	40	2	10	yes	0.68	0.60	0.88	15.8
Diamond	6349	1500	20	40	2	10	yes	**0.87**	**0.62**	**0.92**	22.3
Pink	2679	1500	5	10	2	10	yes	**0.56**	**0.49**	**0.60**	8.3
Star	2787	1500	5	40	2	10	yes	0.60	0.46	**0.85**	10.9

Stake-holder	Design ID	Design Variables: Altitude (km)	Num. Sats	Ant. Area (m^2)	Bandwidth (GHz)	Power (kw)	Tac Comm	"E" MAU	"N" MAU	"R" MAU	Cost B$
All	3423	1500	10	40	2	1.5	yes	**0.75**	**0.47**	0.63	12.8
	3435	1500	10	40	2	10	yes	**0.81**	0.47	**0.92**	14.3
	*6027	1200	10	40	2	10	yes	**0.80**	0.50	**0.92**	14.6
	*519	800	10	40	2	10	yes	0.68	**0.53**	0.88	15.8
	**6349	1500	20	40	2	10	yes	**0.87**	**0.57**	**0.92**	22.3
E+R	2679	1500	5	10	2	10	yes	**0.56**	X	**0.60**	8.3
	2787	1500	5	40	2	10	yes	0.60	X	**0.85**	10.9

These now delivery utility to N with relaxed preferences

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Discussion

- Both applications showed several apparent benefits
  - Rapid development of intuition for the data set
  - Rapid discovery of easy joint solutions
  - Identification of constraints and true tradeoffs
  - Opportunity for real time “what if” relaxation of constraints, as well as negotiated compromise
- Mathematically-based techniques show promise for “seeding” negotiation, as well as provide structured guidance for objective function formulation
  - If DMs disagree with recommendation, objective function can be updated
  - Non-intuitive compromises proposed
  - Identification of driving design variables, or constraining attributes
- Results are indicative, but not exhaustive, further research needed to formally codify the effect

Negotiation rapidly focused on the “true” tradeoffs underlying the search for value-enhancing compromises

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Conclusion

- TS-supported negotiation emerged as a potential use for interactive TSE and has shown promise
- Future work
  - "Players" were seen to enjoy the process, but games could be developed to further improve
  - Should conduct formal "experiments" to codify benefits and costs for using TS-support negotiation in comparison to other methods
  - Balance between automation and human-based methods should be further explored
  - Effect of training, as well as access to different representations of the data on negotiation outcomes

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