



MEDPRAT-SEL: MEDICAL RESOURCE SET SELECTOR SEARCHING HIGH-DIMENSIONALITY SPACE

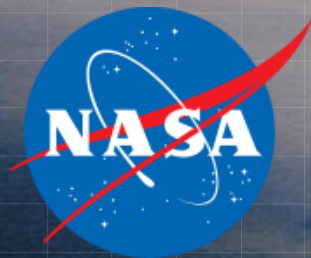
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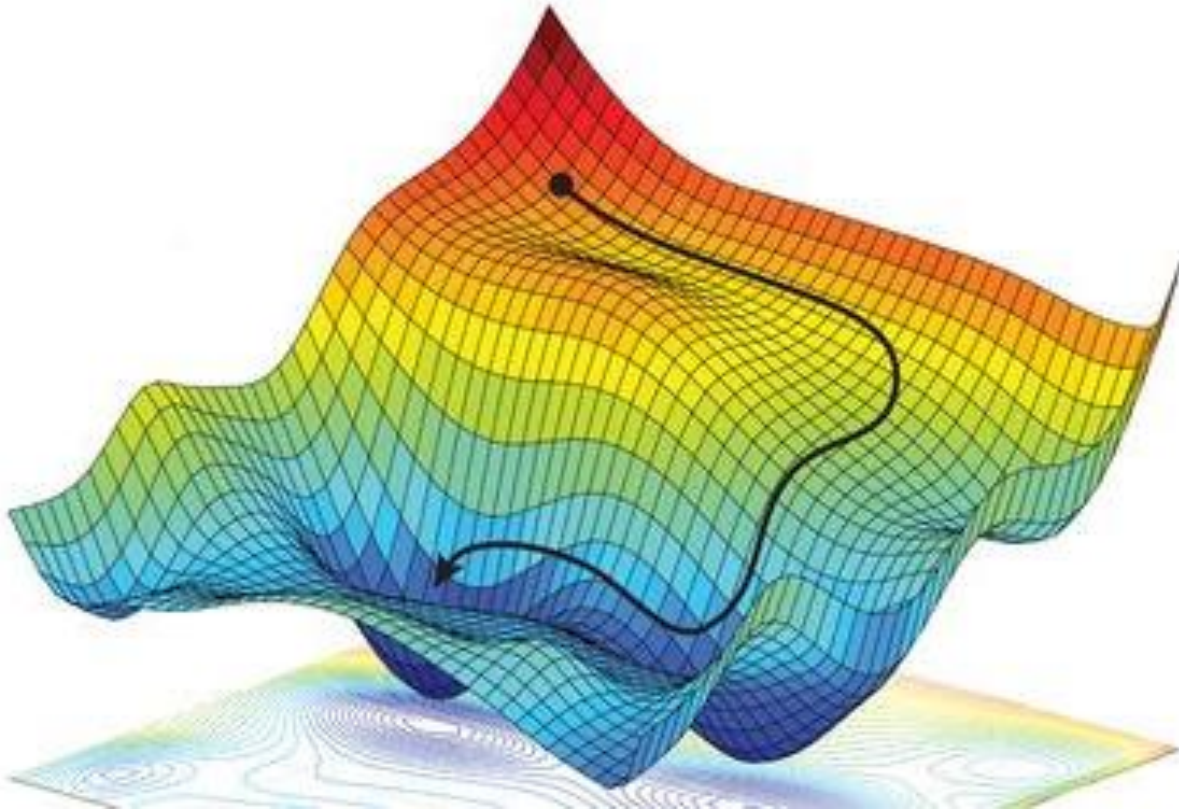
MEDPRAT Overview



- **Medical Extensible Dynamic Probabilistic Risk Assessment Tool**
- Goal: Provide a medical risk prediction tool that is extensible to the majority of exploration missions.

The tool will ideally utilize the available space and terrestrial medical data and human health research to assess space flight medical risk in a manner consistent with other risk measures used in spacecraft and mission design. Also, the tool is tailorable, accommodating new data, new findings, new medical capabilities, new missions and new outcomes.

- Human health research is the process that improves our understanding of medical conditions, medical equipment, space and terrestrial standards and practices.
- This tool provides risk based medical system design information necessary to evaluate new technologies, procedures, research insights and mission plans.

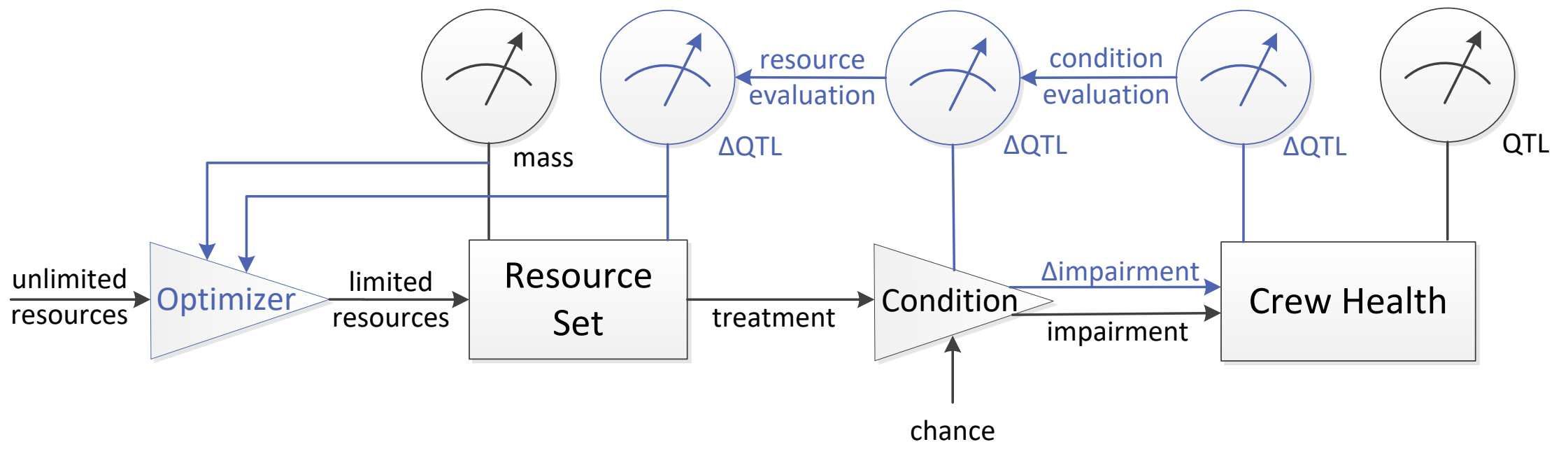


Gradient Descent

- Resource space is massively multi-dimensional (225-D), increasing extrapolation error with larger steps
- The benefit/cost function is not linear but is monotonic
- Need a robust method that supports future data
- Solve like a gradient descent algorithm
- Don't know the differential, but move in the direction away from poorest resources, likely the steepest gradient
- MEDPRAT-SEL removes the poorest resources and tries again; the user chooses the step size



MEDPRAT-SEL Architecture



- Resource-Condition-Health feedback loop
- Blue components and paths are new for MEDPRAT-SEL



Datapaths in Simulator



- **Kinds of Resources**
 - Rate-limited – (momentary only), benefit accrued immediately
 - Quantity-limited – updated over mission time as resources exhausted
- **Δ IFI – relative incremental functional impairment**
 - Functional impairment due a crew's condition
- **Benefit metrics – Δ QTL (from Δ IFI), Δ RTDC, Δ LOCL**
 - at the level of treatment for resource availability relative to no resources
 - at that moment in simulated mission time, so all feature interactions are honored
- **Condition Evaluation**
 - At the end of a trial, metrics accumulated with clinical phases of occurrences of conditions are accumulated for conditions \times cases (best v. worst case)



More Datapaths in Simulator



- **Resource Evaluation**

- Then, conditions \times cases benefit metrics redistributed to resources
- By number of “essential” treatments for condition
- By number of available resources
- For alternates, by available resources and by equivalence

- **Divide resource amounts into parcels**

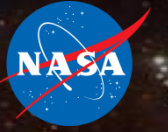
- User provides a parcel size for each resource; the set selector’s resolution of in selecting amounts of that resource
- Each resource amount divided into a number of whole parcels, and a fraction of a last parcel
- Record the number of whole parcels, benefit / parcel of the whole parcels and the benefit of the last parcel

- **For the series of trials**

- Accumulate by whole parcels, benefit / parcel of whole parcels, benefit of last parcel
- Scale for the number of trials and record to file



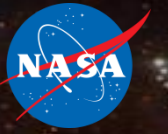
Datapaths in Optimizer



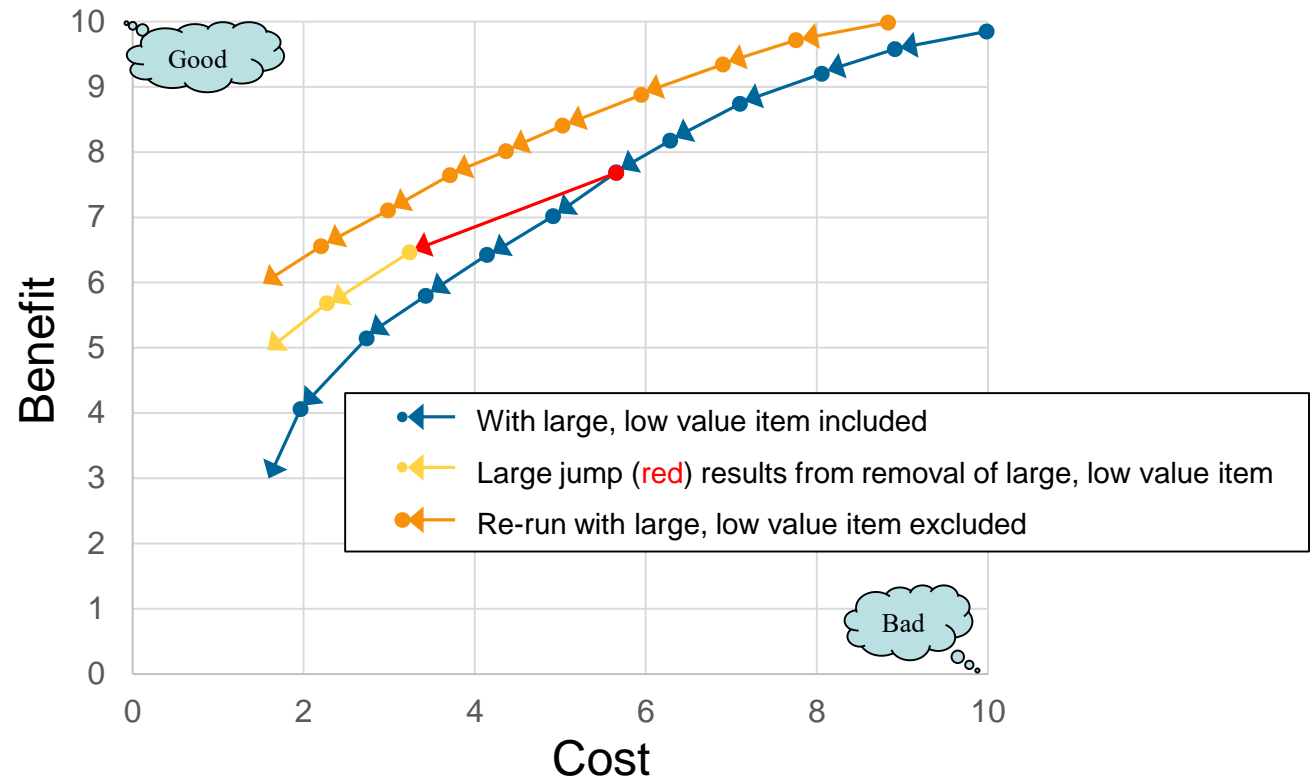
- **Accumulate groups of numbers of parcels**
 - Groups, so data storage size is less dependent of parcel size
 - Cumulative benefit from large to small number of parcels
 - Cost lookup
- **Choose best parcels**
 - Calculate benefit from linear combination of ΔQTL , $\Delta RTDC$, $\Delta LOCL$
 - Calculate cost from linear combination of mass, volume
 - Order groups by benefit / cost
 - Discard poorest
- **Set selector control logic**
 - Iterate until limits met
 - Branch for bulky parcels



Stepping and Branching

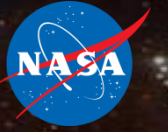


- MEDPRAT-SEL runs simulator and medical resource selector together, iteratively, making incremental changes to resource set
- MEDPRAT-SEL ordinarily makes small steps but a single large item will force a large step
- To avoid errors from this, MEDPRAT-SEL provides a branching option, evaluating sets without and with large items
- The user can access all information about all candidate sets and make a final decision whether to include or exclude a large, low value item at post-processing

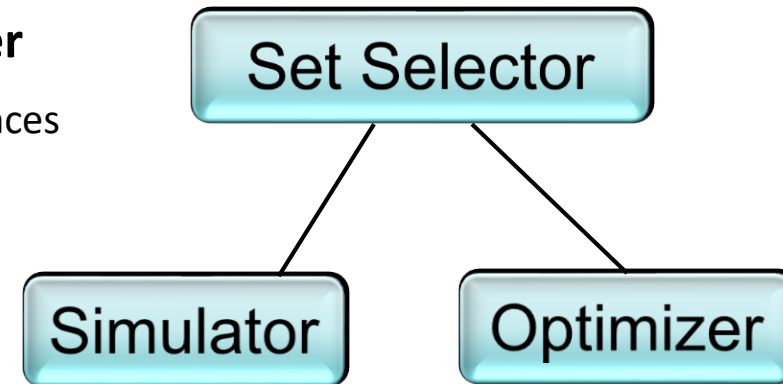




Components



- **Simulator – runs simulated missions**
 - Uses limited medical resource set
 - Collects resource benefit statistics (Δ QTL, Δ RTDC, Δ LOCL)
- **Optimizer – ranks resource instances by benefit / cost**
 - Uses resource benefit statistics
 - Generates reduced medical resource quantities
- **Set Selector – runs simulator and optimizer**
 - Controls limits of simulation-optimization sequences
 - Manages combinations of bulky resources





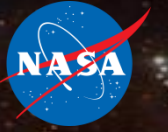
Parameters



- **Number of trials per simulator run**
- **Cost: coefficients for mass, volume in linear combination**
- **Benefit: coefficients for RTDC, LOCL, QTL in linear combination**
- **Control**
 - Benefit-cost factor for reduction of set size by optimization
 - Cost factor (of item relative to set), threshold for larger, bulky items handled by combination
- **Limits on repetition of optimization sequence**
 - Set size reduced to a given cost and/or benefit
 - Number of iterations

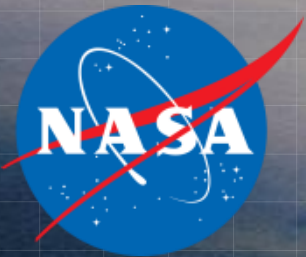


Development Methodologies



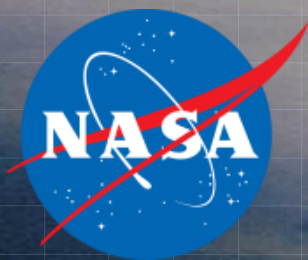
- Agile
 - daily meetings on Slack, in touch with clients
- Object-Oriented Design
- Open-source languages
 - C++, Python; cheaper deployment
- Documentation, 100+ pp.
 - User's Manual, Software Design Doc., Testing Doc.
- Regression tests
 - With every run of simulator
- Solutions built upon existing code

Questions?



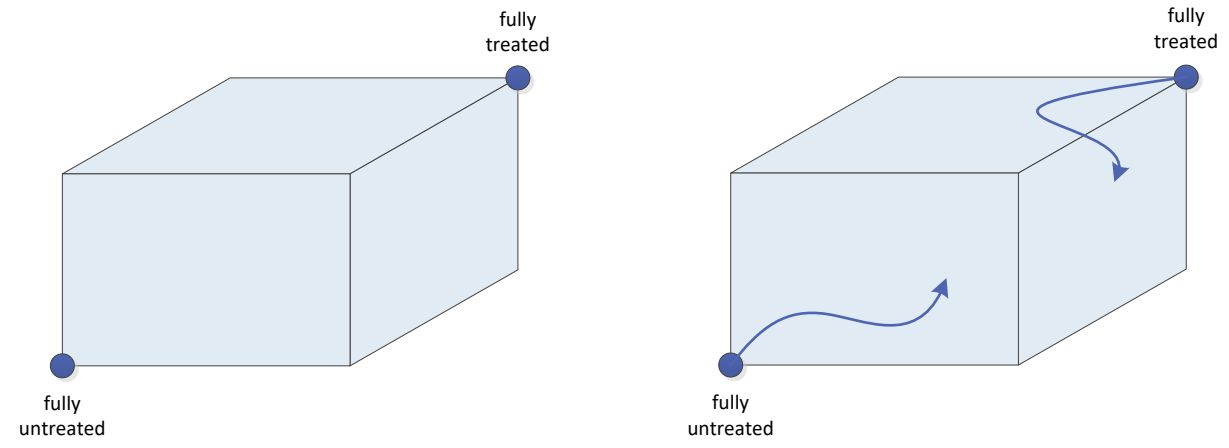
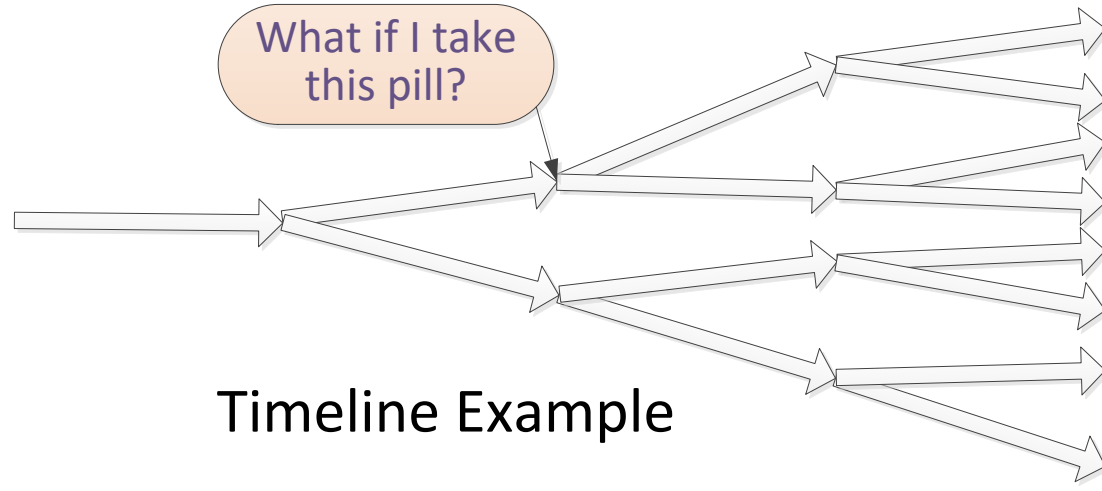
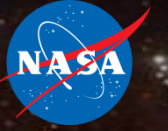


Backup





Set Selector Theory (Old)



Resource Treatment Space



Hazard of Extrapolating Simulator Results



- We saw cases where a fully-untreated, permanently impaired crew was impaired less by a minor condition than if treated
- Estimating Functional Impairment using only fully-untreated and fully-treated data can give distorted results. FI is non-linear.

Functional Impairment	Fully Untreated	Fully Treated	Untreated – Treated
Pre-Existing (FI ₁)	50%	0	50%
New Condition Alone (FI ₂)	33%	25%	8%
Total (FI ₃ = FI ₁ + FI ₂ – FI ₁ FI ₂)	67%	25%	42%
New Condition Attributed (FI ₃ – FI ₁ if FI ₁ > FI ₂ ; FI ₂ if FI ₁ < FI ₂)	17%	25%	-8%

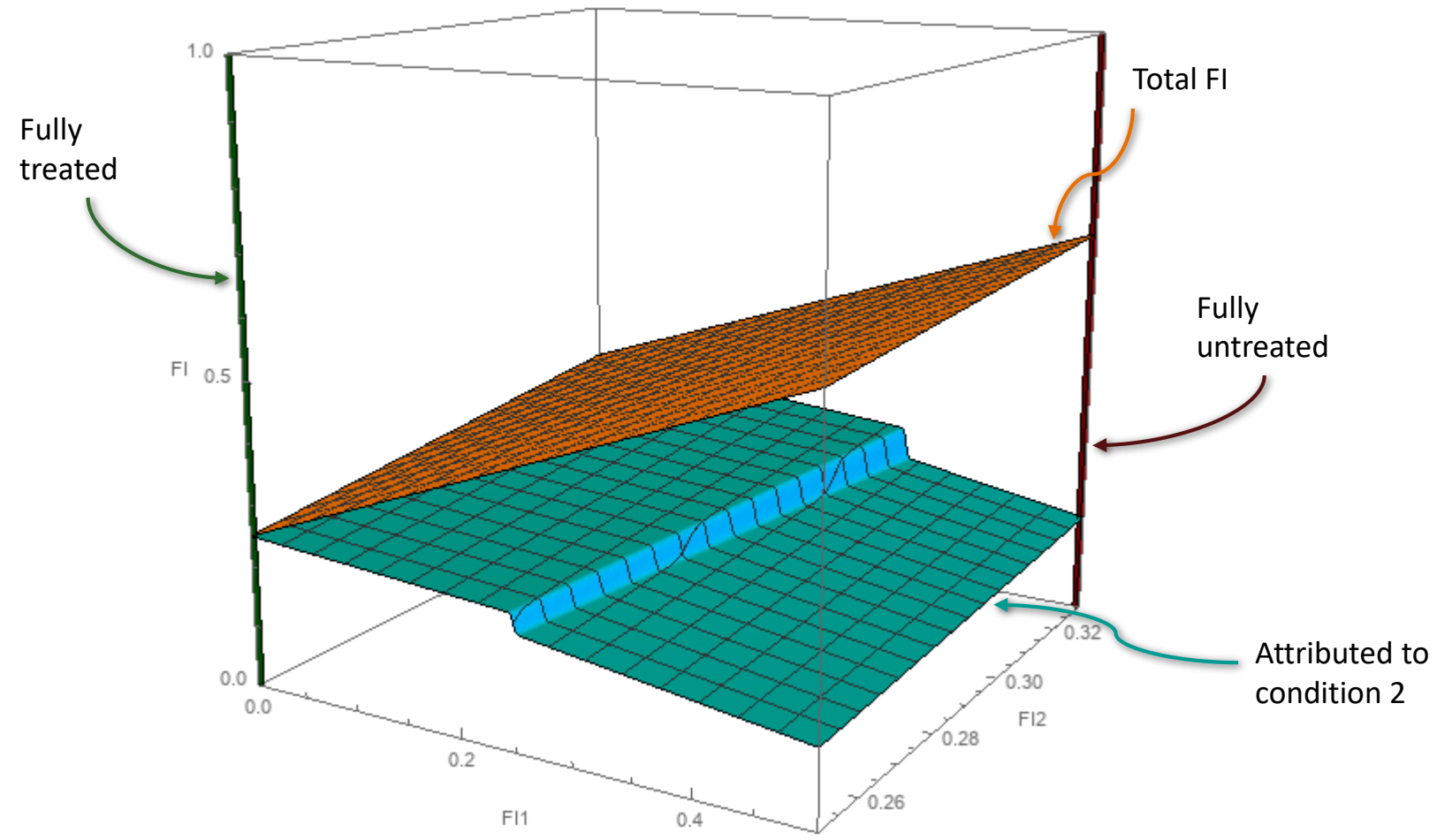
Impairment inputs (orange arrow pointing to 50% and 0)

Standard calculations (green arrow pointing to 67% and 25%)

Unreasonable result (red arrow pointing to -8%)



Graph of Hazard of Extrapolating Results



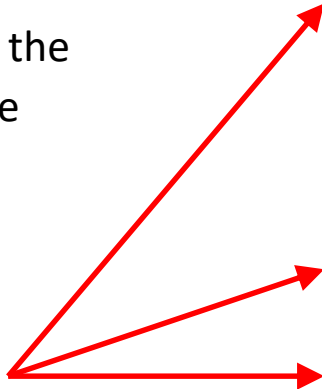
- FI attributed to condition 2 reduces as FI1 increases, and reduces abruptly when FI1 becomes larger than FI2
- In the extreme, less FI is attributed to condition 2 when untreated rather than treated



Interaction of Features in the Model



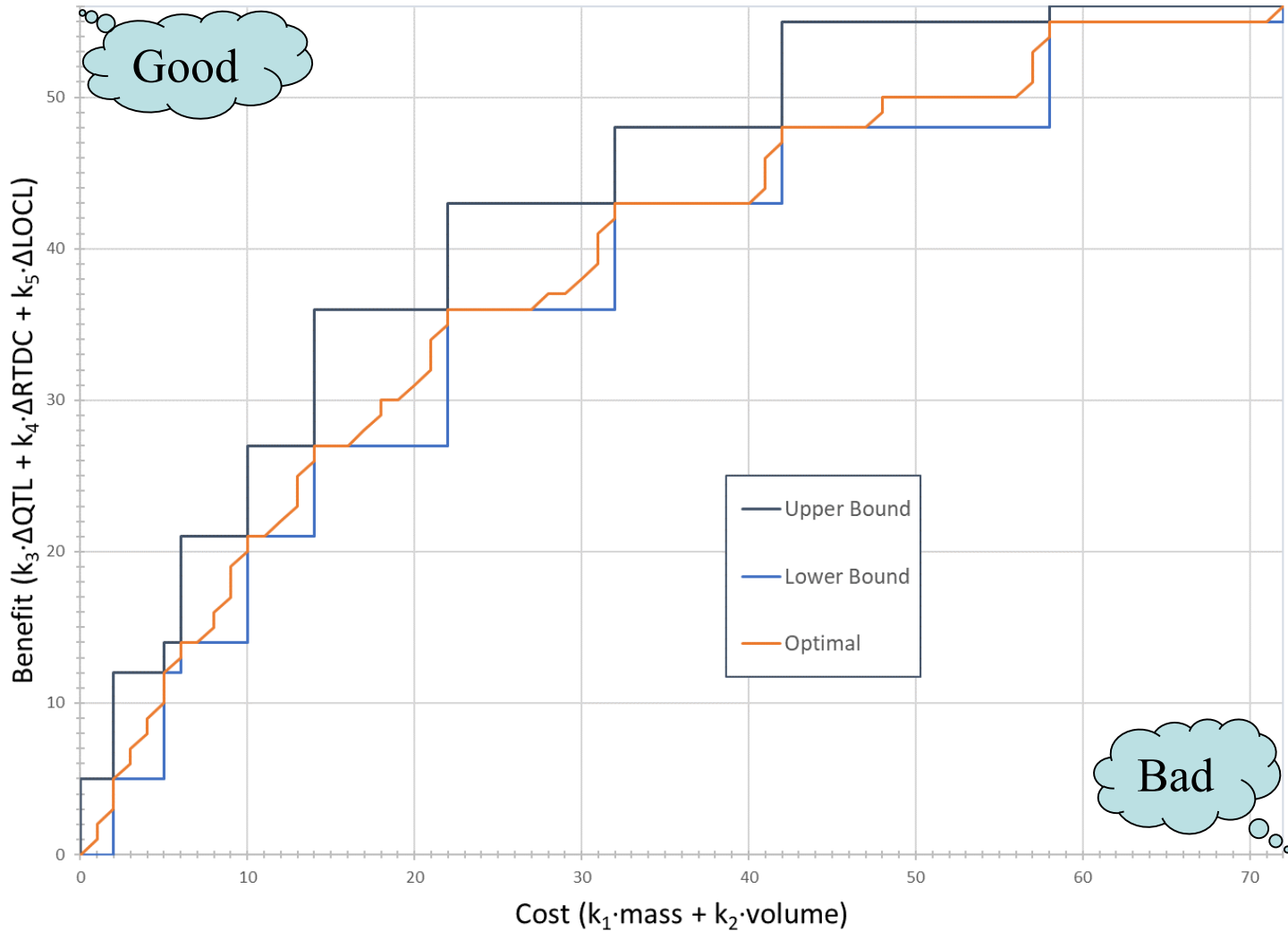
- The interactions and non-linearities in the model make larger extrapolations less accurate
- Benefit of a resource depends on the presence of other resources in the set
- May lead to errors in selecting medical resources
- Some features have limited representation in fully-treated or fully-untreated paradigms



Feature Name	Impact	Interaction	Invariants
Treatment	Occurrence, QTL	Resource to condition	One crew
Anti-overdose	Resource	Condition to condition	One resource, one crew
Scarcity of resources	Condition	Crew to crew	One resource
Cumulative FI	QTL	Occurrence to occurrence	One crew
One occurrence of condition at a time	Incidence rate	Occurrence to occurrence	One crew
RTDC, LOCL	Resources, QTL	Occurrence to conditions	One crew
Alternate Treatment	Resources	Resource to resource	One condition, one crew
Susceptibility	Incidence rate	Condition to condition	One crew
Contagion	Incidence rate	Crew to crew	One condition



Optimization Example



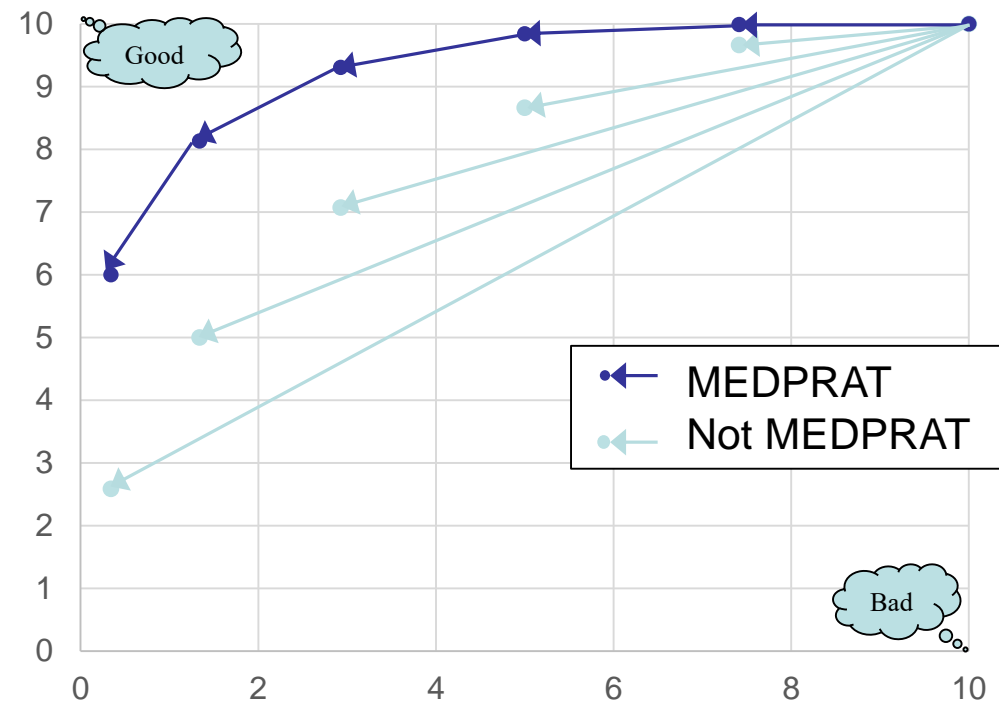
- Each resource (rectangle) has a benefit (height) and cost (width)
- A set with the best (benefit/cost) for a given cost or benefit does not necessarily consist of the best (benefit/cost) resources
- The best resources come within one resource of a best set for a given cost or benefit target, and if that resource is fungible, the set is best
- Benefit of a resource depends on the presence of other resources in the set
- Uncertainty precludes optimality



Extrapolation across Resource Space



- MEDPRAT runs simulator and medical resource selector together, iteratively, making incremental changes to resource set
- Resource space is massively multi-dimensional, increasing extrapolation error
- The benefit/cost function is not linear but is monotonic
- Need a robust method that supports future data
- MEDPRAT-SEL removes the worst resources and tries again; the user chooses the step size





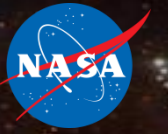
Usage Notes (Gotchas)



- **Execution time is very sensitive to cost factor**
 - After increasing cost factor, use quick simulator runs (1k trials) to see how long it takes. But quick simulator runs are noisy and introduce some additional execution time
- **In resource source file, use constraints on quantities of resources**
 - Set selector will not produce a set outside of the given limits
 - Initial_Quantity field – maximum quantity in set. Use NaN to leave unconstrained
 - Keep_Quantity field – minimum quantity in set. Use 0 to leave unconstrained
- **In resource source file, use parcel size to control resolution of MEDPRAT-SEL**
- **Optimizer makes decisions based on *estimated* benefit**
 - Set selector results are taken directly from the simulator
 - After running the set selector, every set is available to be simulated again to get more detailed results
- **More research / experimentation, better data needed**



How to Use MEDPRAT-SEL



- **Get good input database and set selector program parameters**
 - Software results are no better than the inputs
- **Low-hanging fruit**
 - Dismiss uncompetitive resources; lock-in large, high-value resources early
 - Use shorter simulator runs early
- **When approaching targets, let the tool work**
 - Reduce cost factor to try more combinations of items
 - Lengthen simulator runs to get accurate results for rare events
- **Run very competitive sets through simulator again**
 - Get detailed reports, do sensitivity analyses, etc.
- **Once you have a good set, don't believe it**
 - Ask what-if questions, make small modifications and rerun simulator
 - Find problems with the model and help build a better one



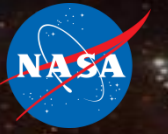
Actual Results – Summary File



Set ID	Cost	Benefit	Absolute Benefit	Mass	Volume	RTDC	LOCL	QTL	Parent Set ID	Branch Set ID	Base Set ID	Resource ID	Initial Quantity
0	0	0	-73.7402	0	0	0.423	0.003	73.7402	0	0	0	NaN	NaN
1	NaN	58.5885	-15.1517	NaN	NaN	0.027	0.001	15.1517	1	1	1	NaN	NaN
2	39.33884	NaN	NaN	39.33884	66369.36	NaN	NaN	NaN	1	1	1	NaN	NaN
3	39.33884	NaN	NaN	39.33884	66369.36	NaN	NaN	NaN	2	2	1	221	1
4	39.33884	NaN	NaN	39.33884	66369.36	NaN	NaN	NaN	3	3	1	119	1
5	39.33884	58.2674	-15.4728	39.33884	66369.36	0.042	0.001	15.4728	4	4	1	115	1
6	34.98373	58.843	-14.8972	34.98373	42446.96	0.029	0.001	14.8972	5	4	1	115	1
7	31.30079	58.6368	-15.1034	31.30079	34710.7	0.038	0.003	15.1034	6	4	1	115	1
8	28.41846	57.3654	-16.3748	28.41846	31973.94	0.047	0	16.3748	7	4	1	115	1
9	26.32716	55.0675	-18.6727	26.32716	26316.96	0.079	0	18.6727	8	4	1	115	1
10	25.01703	51.1981	-22.5421	25.01703	22838.72	0.13	0.003	22.5421	9	4	1	115	1
11	24.34167	44.7334	-29.0068	24.34167	18174.58	0.173	0.003	29.0068	10	4	1	115	1
12	23.97167	41.6486	-32.0916	23.97167	17965	0.195	0.007	32.0916	11	4	1	115	1
13	23.75735	38.064	-35.6762	23.75735	17804.91	0.217	0.004	35.6762	12	4	1	115	1
14	23.68036	36.0943	-37.6459	23.68036	17722.76	0.257	0.005	37.6459	13	4	1	115	1
15	NaN	58.8413	-14.8989	NaN	NaN	0.032	0	14.8989	4	4	15	115	0



MEDPRAT-SEL Preliminary Results



Preferred to minimize QTL rather than LOCL

1. Eyewash waste water bag (2)
2. Space station eye wash
3. Eye wash goggles & tubing
4. Blood pressure cuff – large
5. Panoptic ophthalmoscope
6. SAM splint - leg/arm splint

7. Smooth forceps
8. Scissors – trauma
9. Skin staple remover
10. Afrin (Oxymetazoline) 0.05% 15mL bottle (3)

Preferred to minimize LOCL rather than QTL

1. IV fluid 1L (1000 mL) (2)
2. Ambu bag and mask
3. Intraosseous injection device
4. Suction device
5. Variable oxygen system
6. ILMA endotracheal tube 7.0/7.5 & endotracheal tube 7.0/8.0
7. Albuterol inhaler (Proventil) 90 mcg, 6.7 gm (2)
8. Dexamethasone (Decadron) 10 mg injectable (5)
9. Suction device syringe
10. Adrenaline (epinephrine 1:10000) 10mL

- Top ten resources by **total mass**; 5 kg medical resource set
- Lunar DRM: 6 crew, 14 days, 8 EVA
- 10,000 trials per run; 10% mass decrease per run



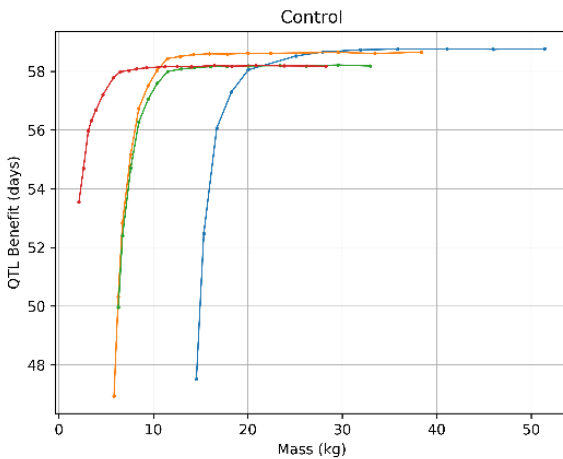
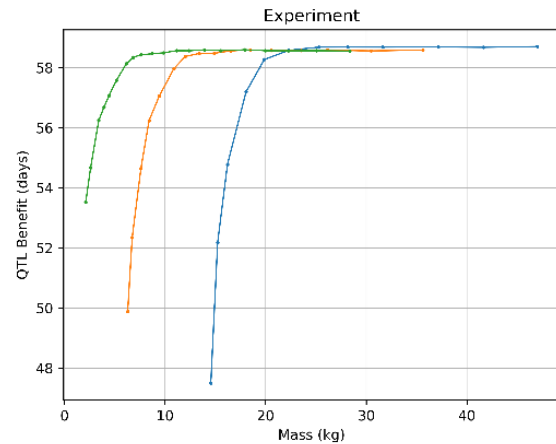
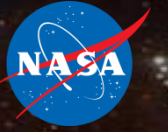
Demo Trade Study



- **Pilot of a pilot trade study**
 - Based on planned trade study by pilot project
- **Based on 42 day Gateway mission including RTDC and PEC**
- **A bulky resource *X* was selected as candidate for miniaturization research:**
 - How much would productive time increase if resource *X* could be miniaturized to 10% mass for Gateway mission?



Results



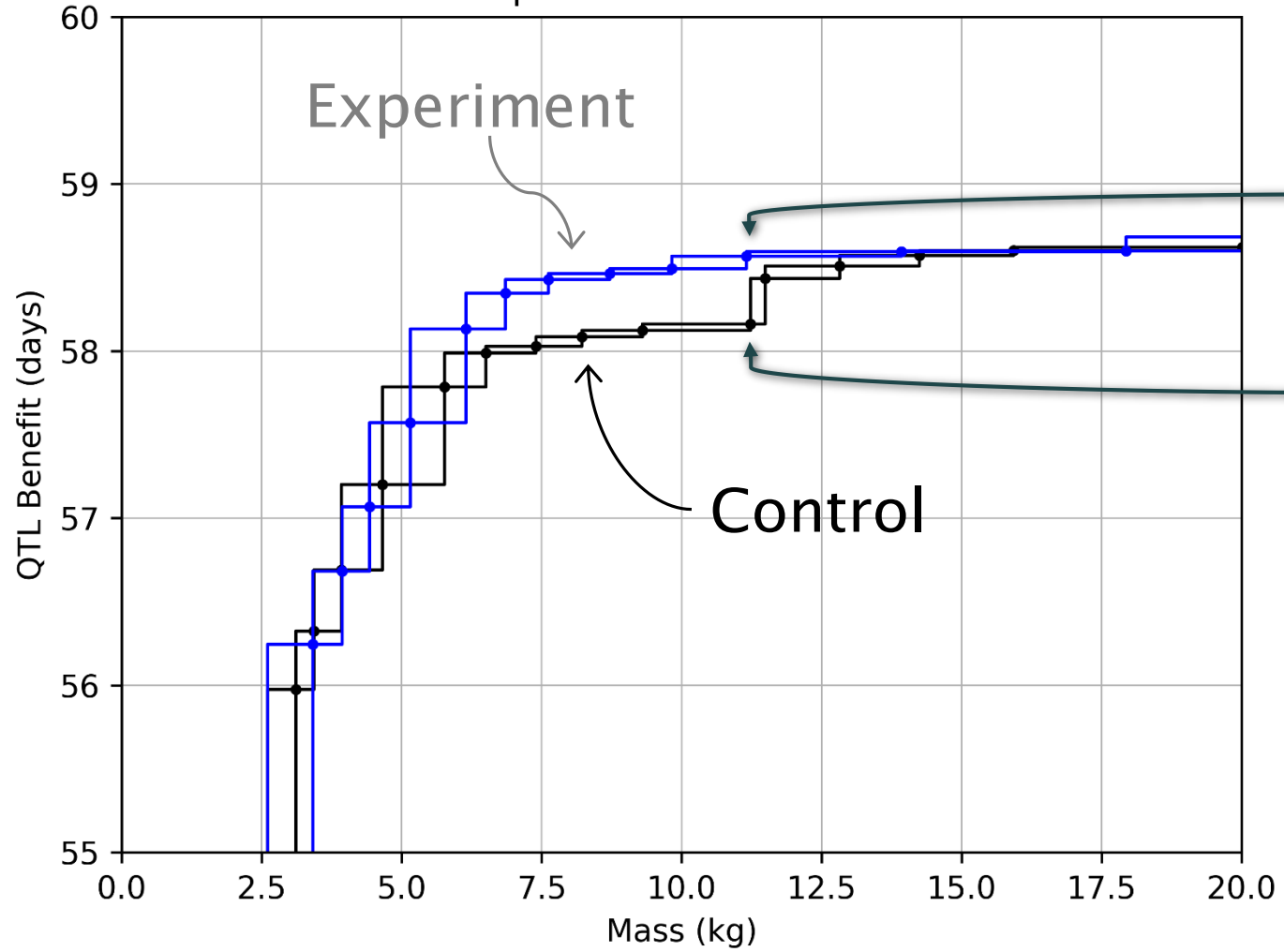
- Each point represents 1M mission simulations
- Each line represents optimization by removing high cost, low benefit resource instances
- Different lines represent different combinations of high cost resource quantities
- Horizontal axis is mass in kg of entire set
- Vertical axis is Quality Time Lost (QTL) in days relative to untreated (empty set). Benefit of treatment is upward.
- Upper left is good; lower right is bad.
- Pair of charts: control case, experiment case.



MEDPRAT-SEL Trade Study Prototype



Experiment vs. Control



- How does productive time increase if resource X could be miniaturized to 10% mass?
- What resources are taken in sets of comparable mass?
 - Experimental set only (1 ea): resource X, Fluorescein 1 mg strips
 - Control set only (1 ea): suction device, dental elevator - 301 (i), dental elevator - 34s (j), foam electrodes, Lopressor (Metoprolol) 50 mg, Adrenaline (Epinephrine 1:10000) 10 ml, Valium (Diazepam) 5 mg/ml, 2 ml syringe, Lotrimin AF cream (Clotrimazole) 1%, 30 gm tube, dental adhesive (76 gms), Promethazine injectable (Phenergan) 50 mg/ml single dose vial, Vicodin HP (hydrocodone/ acetaminophen HP) 10 mg/660 mg, ILMA cue card, Mupirocin (Bactroban) 2%, 22 gm tube, Phenergan (Promethazine tablet) 25 mg, Motrin (Ibuprofen) 400mg, Dulcolax (Bisacodyl) tablet 5mg, refresh artificial tears (Carboxymethylcellulose) 0.5%, 0.4ml bottle, Fluocinonide 0.05%, 30gm tube, Tylenol (Acetaminophen) 325 mg, Sudafed 12 hour (Pseudoephedrine) 120 mg, Imodium (Loperamide HCL) 2 mg tablet, Prednisone 20 mg, Moxifloxacin (Avelox) 0.5%, 3ml bottle