Systems Engineering Advancement Research Initiative

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Trading Project Costs and Benefits in Multi-Attribute Tradespace Exploration

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Loughborough, UK

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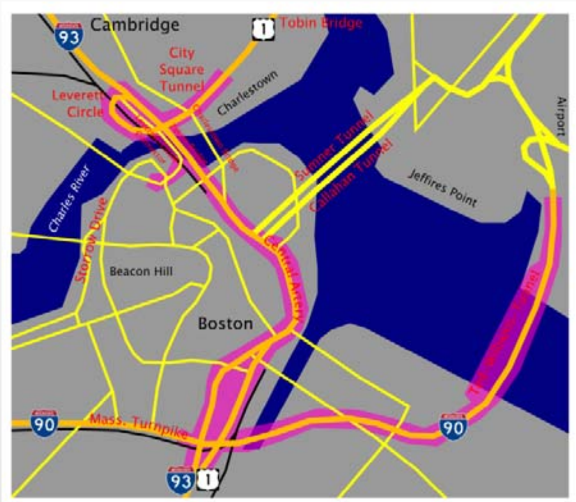
Complexities in engineering systems

Big Dig

(Boston, ca. 1982-2007)



Projected cost (1985): $2.8bn

Cost spent (2007): $22 bn

(incl. interest and inflation)

Complexities shared between different domains

- Long lifecycles
- High initial investments
- Unique designs
- Long-term lock-in of consequences of bad designs

Exploration of large number of designs during the conceptual design phase increases the odds of getting on the right track for developing a “good” design.

Congressman Barney Frank: "Rather than lower the expressway, wouldn't it be cheaper to raise the city?"

Cost-Benefit Analysis in transportation planning

Cost-Benefit Analysis (CBA) is a preferred method for transportation project evaluation.

Benefits

- Certain transparency for project evaluation
- Comparison of different projects on a common scale

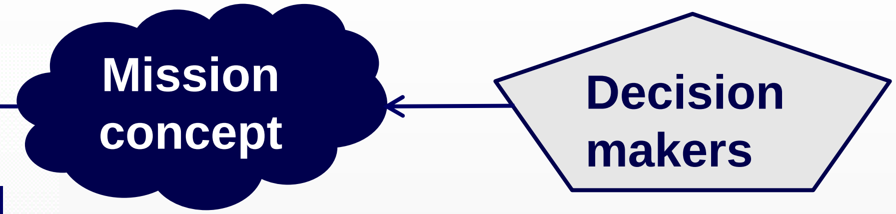
Shortcomings

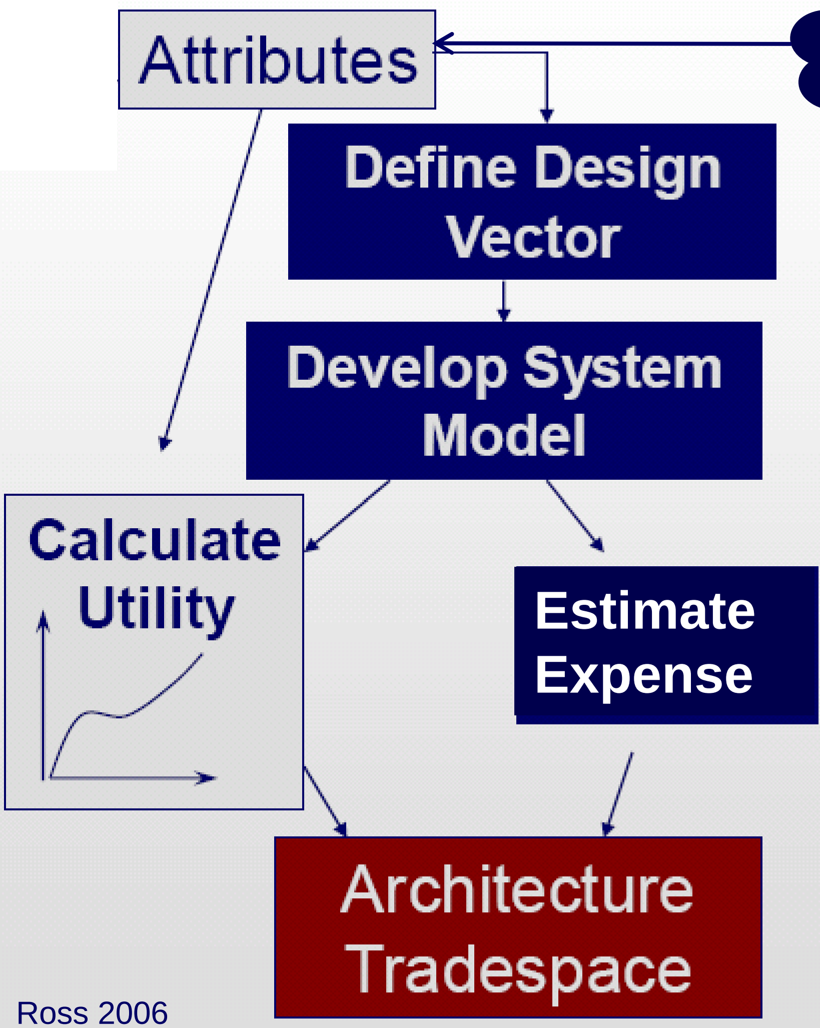
- Introduction of critical value assumptions (discounting of non-monetary goods, linear utility assumption)
- Interpersonal utility comparisons and loss of information about the distribution of costs and benefits
- Aggregation of certain and uncertain costs on a common scale

One source of error is the comparison of only one, or a limited number of alternatives, to the base case (biasing, lumping together).

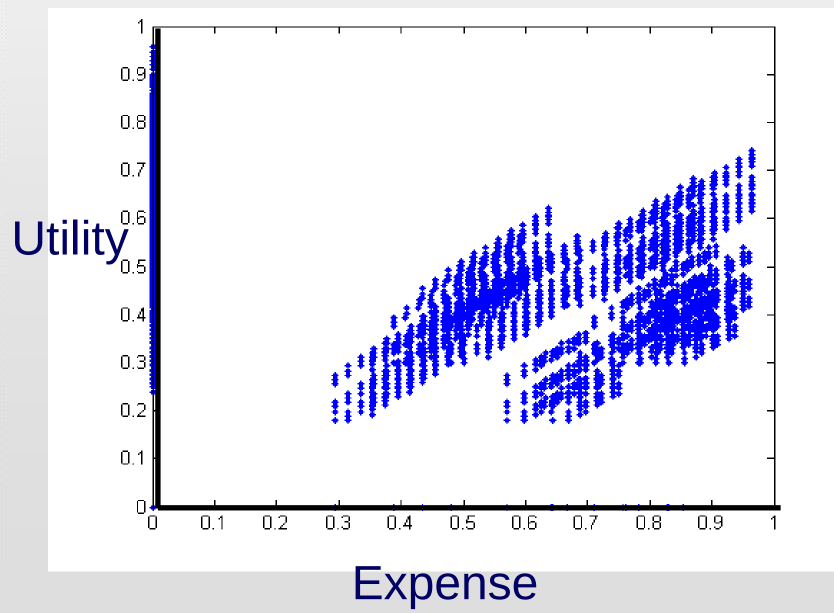
US Federal Highway Administration: Need to explore "full range of alternatives". Without a systematic method sufficient exploration of alternatives is left to the judgment and expertise of the analyst.

MATE-Overview





Expense function: Aggregation of several cost types to a single number between 0 and 1, akin to the idea of negative utility



Ross 2006

Research questions

Multi-Attribute Tradespace Exploration (MATE) allows the systematic exploration of a large number of designs in the conceptual design phase.

- Can MATE, developed using aerospace applications, be used for applications in the transportation domain?
- Can MATE help to mitigate some of the shortcomings of CBA?

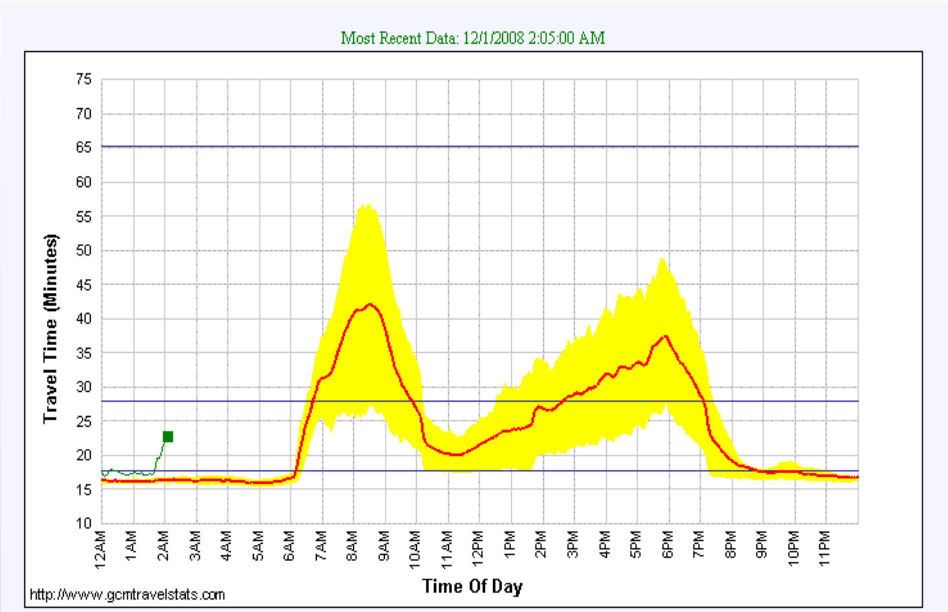
Approach

(1) Introduction to case study: Airport Express for Chicago
(2) Identification of stakeholders
(3) Elicitation of stakeholder attributes using both CBA and MATE
(4) Generation of alternative system concepts
(5) Calculation of Cost-Benefit Values for different design options (CBA)
(6) Calculation of aggregated Utility-Expense and plot of tradespaces for different design options (MATE)
(7) Evaluation of the best alternative using both methods
(8) Discussion of the shortcomings of CBA and their mitigation through MATE

1. Introduction
Airport Access in Chicago

Problems with existing airport access options

Kennedy Expressway



Source: Gary- Chicago- Milwaukee Corridor Travel Statistics

•Frequent and highly variant congestion

•Travel time 25-60 min

Public Transportation

Source: Wikipedia

•Hike with luggage

•Travel time 60 min, 15 stops

2. Identification of stakeholders

Decision-making stakeholders

- City of Chicago
- Chicago Transit Authority (CTA)
- Private Operator

Non-decision making stakeholders

- Passengers
- Chicago Public
- Residents adjacent to tracks
- O'Hare International Airport
- Airlines

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Determine which system will be built

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Preferences only indirectly accounted for through decision-making stakeholders

3. Stakeholder attributes

1. MATE- Elicitation through interviews with proxy representatives for stakeholders

City of Chicago

Weight	High-level Attributes	Depend on
0.12	Estimated tax base change	Land value ->Ridership-> Attractiveness -> *Quality of Service (QOS)*
0.12	Generation of employment	Initial costs, Attractiveness -> *QOS*
0.12	Availability of outside funding	*City's cost share*
0.1	Attraction of visitors	Attractiveness -> *QOS*
0.1	Equity	*City's initial costs*
0.56		

CTA

Weight	High-level Attributes	Depend on
0.2	Up front investment required from CTA	*CTA initial costs*
0.2	Impact on current operations- capacity	Shared tracks with Blue Line
0.2	Probability of recurring delays to curr. operations	Shared tracks with Blue Line
0.1	Maintainability	*Span of service*
0.7		

For operationality in MATE analysis

1. Only accounted for top 4 or 5 attributes for clarity
2. Broke high-level attributes down into those that can be influenced by technical design

Private Operator

Weight	High-level attributes	Depend on
0.4	Return on investment pre-tax	Ridership-> *QOS*, fares, *concession payment, operating costs*
0.15	Freedom of concessionaire to make operational changes	*Freedom to make changes*
0.15	Competition agreements	*Competition agreements*
0.1	Concession payment	*Concession payment*
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3. Stakeholder attributes

2. CBA- Elicitation through use of guidelines for typically relevant costs and benefits, Incl. non-monetary ones (Federal Highway Administration, CalTrans)

Benefits	Costs
First order effects	
Travel time savings (speed and reliability)	Capital cost
- To Airport travelers	Operating cost
- To Blue Line riders	Delays to Blue Line passengers
- To drivers (congestion relief on Kennedy)	Delays to drivers on Kennedy Expressway
Emission reduction	Noise to residents
	Adverse neighborhood impacts from construction
Second order effects	
Long-term job generation	Job losses (from changes in operation at CTA, cab drivers)
Attraction of new business development	Loss of property value in neighborhoods impacted by noise
Jobs from construction and from airport express	
Attraction of businesses and new development	
Increase in property value around downtown terminal	

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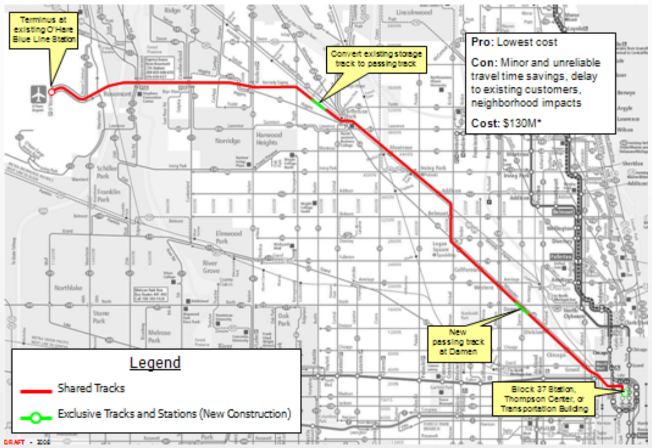
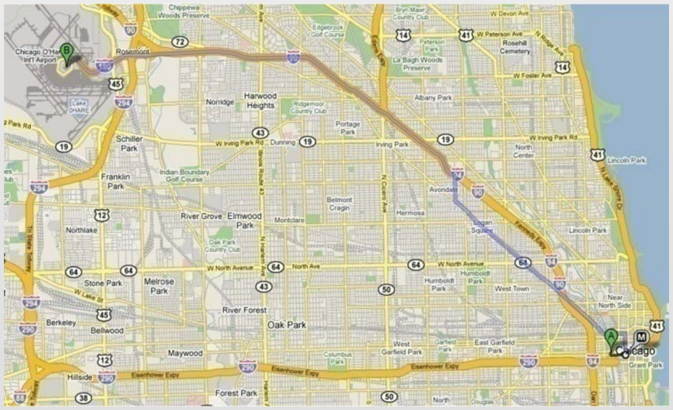
4. Generation of alternative system concepts



Route 1 (eliminated) Source: CTA

Route 2 Source: CTA

Bus Rapid Transit (BRT)

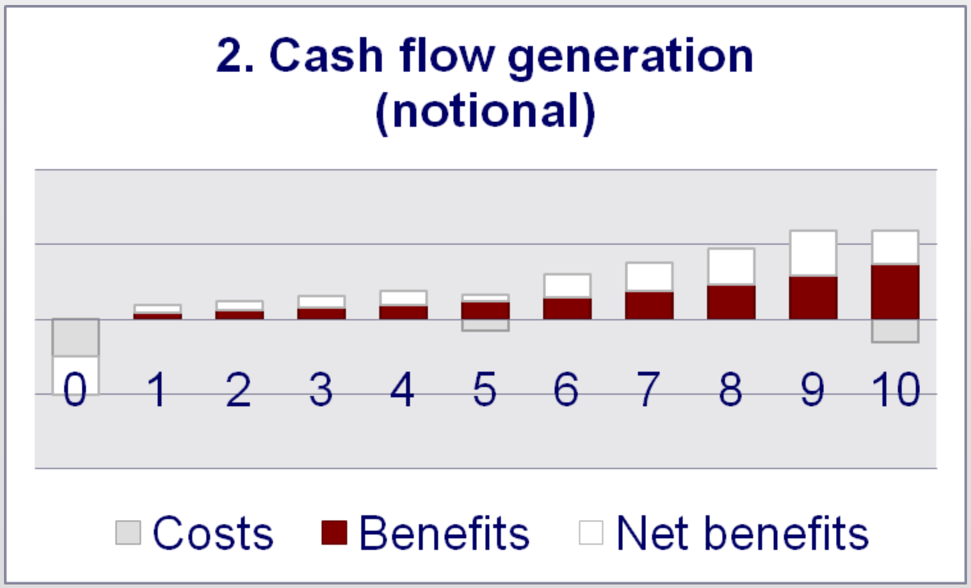


Blue Line Switch (BLS)

5. Calculate Aggregate Cost-Benefit

1. Models
1.Construction expenses (year 0)
2.Operating expenses (annually)
3.Travel time savings (annually)
4. Emissions savings (annually)
5.Fleet expansion and replacement Expenses (every 10- 15 years)

3. Net Present Value (NPV) calculation of discounted Cost-Benefit



5. Calculate Aggregate Cost-Benefit

1. Models

1.Construction expenses

Source: CTA technical studies and analogy building for BRT

2.Operating expenses

Source: Model based on vehicle miles traveled, fuel, electricity, overhead, operator wages

3.Travel time savings

Source: Travel time savings model based on higher flow through decongestion on Kennedy, shorter expected average travel times through shorter headways and faster travel for public transportation

4. Emissions savings

Source: CalTrans emissions model based on monetized costs per vehicle mile traveled

5. Fleet expansion and replacement

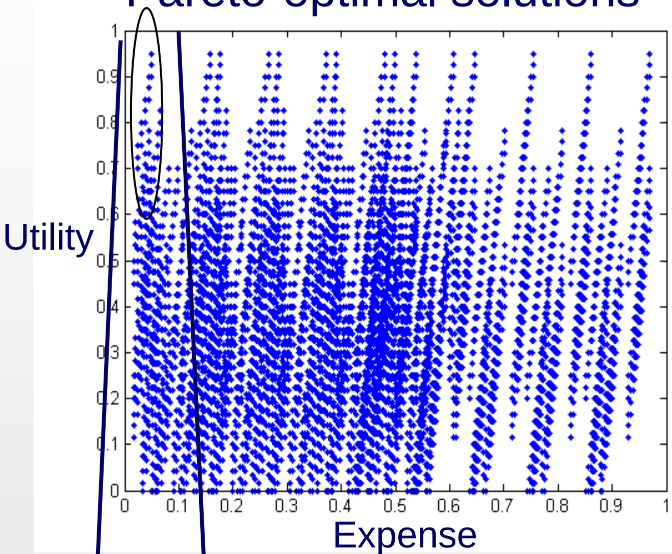
3. Net Present Value (NPV) calculation of Cost-Benefit

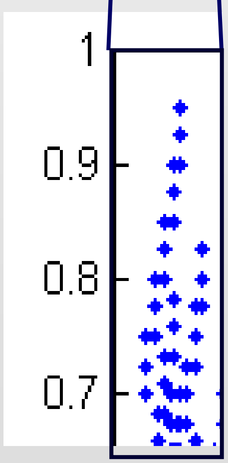
In mn 2008 $	Base case	Route 2	BRT	BLS
DR=7%	0	-97	-70	718
DR=10%	0	170	-37	447

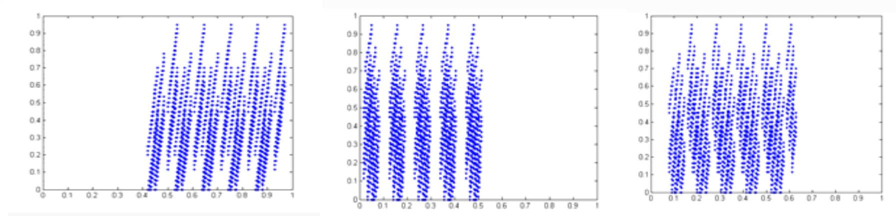
Smaller is better

2. Cash Flow generation

6. MATE Analysis: City of Chicago







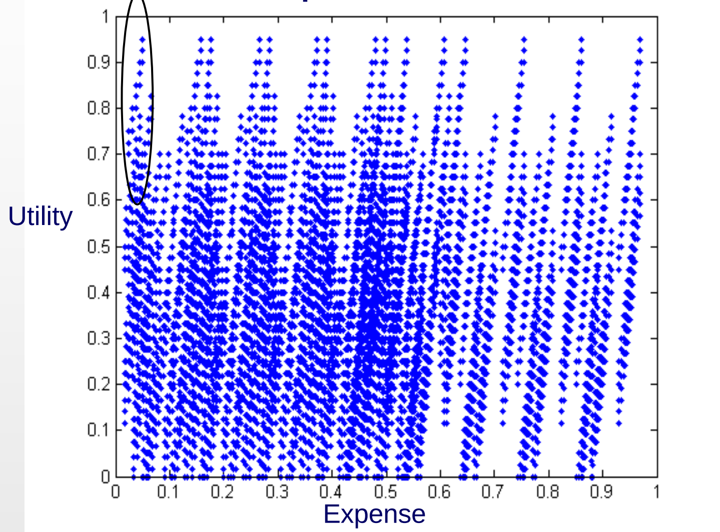
Shapes for individual corridors

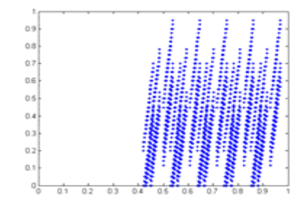
(See paper for ranges and measures of attributes and design variables)

	Attributes		
Design Variables	**QOS**	**City's initial cost**	**City's cost share**
Concept	0	9	0
Fare level	9	0	0
Frequency	9	3	0
Travel time	9	3	0
Amenities	9	3	0
Span of service	9	0	0
City's cost share	0	0	9

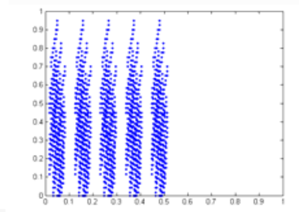
6. MATE Analysis: City of Chicago

Pareto-optimal solutions

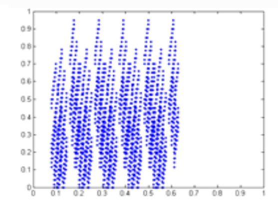




Route 2



BRT



BLS

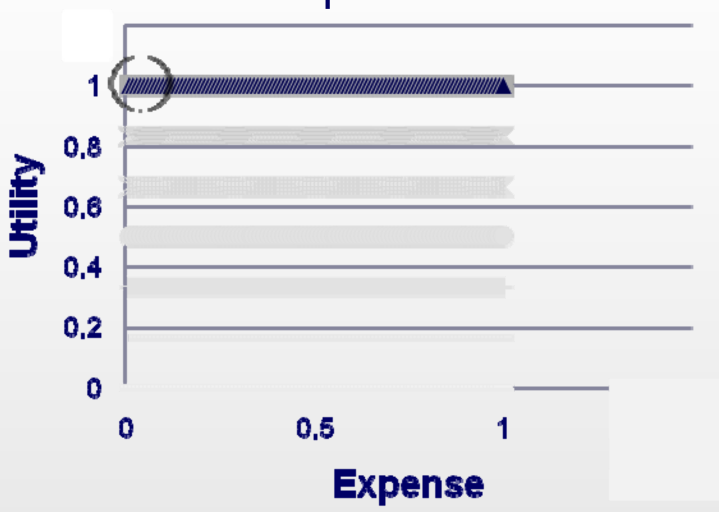
Shapes for individual corridors

BRT is the preferred concept because it has the lowest up front cost.

High levels of Quality of Service are preferred since they come at little initial expense.

6. MATE Analysis: Chicago Transit Authority

Pareto-optimal solutions

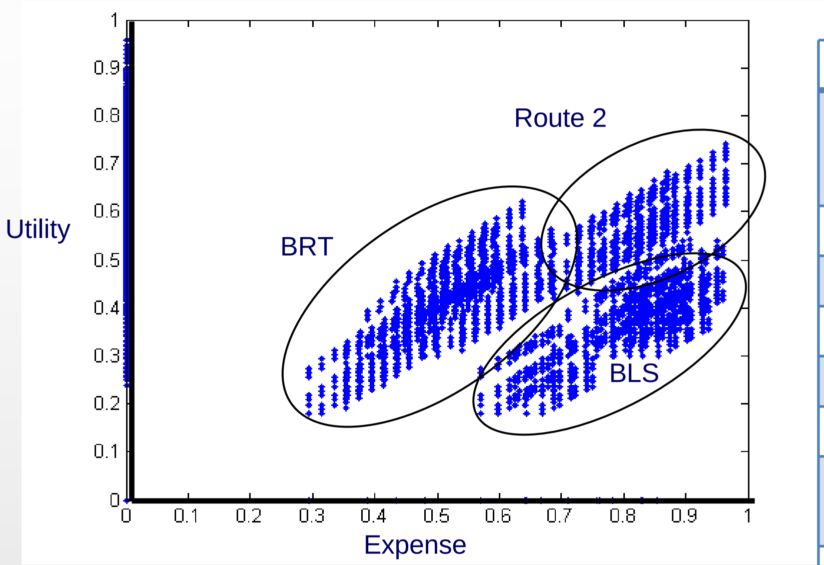


	Attributes	
Design Variables	**CTA initial cost**	**Span of service**
Up front investment req from CTA	9	0
Impact on current operations	0	0
Probability for recurring delays to existing Blue Line trains	0	0
Span of service	0	9

After elimination of Route 1, two independent attributes remain.

Preference for low initial investment and short span of service do not correspond to any specific design concept.

6. MATE Analysis: Private Operator



	Attributes				
Design variables	**Operat cost**	**Con-cession**	**QOS**	**Freedom**	**Comp Agreem.**
Concept	9	9	0	0	0
Fare level	0	0	9	0	0
Frequency	9	0	9	0	0
Travel time	3	0	9	0	0
Amenities	0	0	9	0	0
Span of service	3	0	9	0	0
Freedom to make changes	0	3	0	9	0
Competition agreement	0	3	0	0	9

BRT and Route 2 are optimal designs depending on desired level of utility.

A number of attributes are non-monetary and non-technical.

7. Determination of best alternative (concept choice)

CBA

• BRT is the only solution that provides net benefits to society independent of the discount rate
• Advantageousness of Route 2 depends on discount rate

MATE

• Private Operator: BRT emerges as the best option for the Private Operator until a utility of approximately 0.6., above that level Route 2 is the best option
• CTA: No attributes impacted by concept design variable
• City of Chicago: Favoring BRT as cheapest option

No clear dominant design concept, BRT is cheaper and Route 2 has higher utility and higher benefits later in the lifecycle.

The Blue Line Switch Option however is dominated in both analyses.

8. Evaluation of shortcomings of CBA

Shortcomings of CBA

- Introduction of critical value assumptions
- Interpersonal utility comparisons and loss of distributional informationof costs and benefits
- Aggregation of certain and uncertain costs on a common scale

Benefits of using MATE in Chicago Airport Express Case Study

- Discount rate in determining advantageousness of (Route 2) project (discounting of travel time savings) is avoided
- Revelation of insightful preference patterns of stakeholders through MATE
- Possibility for further exploration of impact of different cost types (different "colors of money" and non-monetary costs) through use of single-cost functions

MATE has the potential to mitigate some of the shortcomings of CBA by providing high-level architectural guidance early on in the planning process.

Limitations of MATE and CBA

CBA

- is used to decide whether total costs to society outweigh total benefits (good project or not), tries to do project justice (tangible and intangible benefits and costs)
- is one tool within a suite of techniques (EIS, Financial Analysis)
- is NOT a creative design method
- prescriptive

MATE

- represents agencies' views, including potential principal-agent biases
- introduction of environmental/public interest stakeholder possible, but capture of utilities for those stakeholders moves away from structured utility interviews with actual decision makers
- descriptive

Conclusions and future work

Conclusion

MATE can, with a few expansions, be applied to transportation problems. Deeper insight into stakeholders' preference patterns are gained and a large number of designs can be assessed at a high level to feed into more detailed analyses. Being a descriptive method however, no mechanisms are in place in MATE to ensure that represented public interests are sufficiently taken into account. The prescriptive CBA method seeks to do the project justice by assuring that all tangible and intangible costs and benefits be captured, some of which may be easily overlooked.

Future work

Combine MATE and CBA in joint process to leverage benefits of both

Thank you for your attention.

Questions?