Trading Project Costs and Benefits in Multi-Attribute Tradespace Exploration

Julia Nickel[1], Adam M. Ross[2] and Donna H. Rhodes[3]

[1] Massachusetts Institute of Technology, USA, juni@mit.edu
[2] Massachusetts Institute of Technology, USA, adamross@mit.edu
[3] Massachusetts Institute of Technology, USA, rhodes@mit.edu

Abstract

Classical Cost-Benefit Analysis (CBA) is a preferred method for the evaluation of large-scale infrastructure investment projects in the private and government sector. This paper proposes the use of a method for tradespace exploration as an iterative to classical CBA to help overcome some of its shortcomings. Multi-Attribute Tradespace Exploration (MATE), a method for system decision making and design, allows the tradeoff of both desirable and undesirable system (and project) attributes. Undesirable attributes impose "costs" on stakeholders, which can be traded off in a similar manner to desirable attributes, which supply "benefits." This method possesses several advantages for the treatment of monetary and non-monetary attribute types compared to classical CBA. Utility for different stakeholders is kept separate, avoiding controversial interpersonal utility aggregation and comparison. Tradeoffs among different types of non-monetary attributes are made explicit. Large numbers of designs can be assessed rapidly, allowing for the exploration of patterns in the tradespaces that may help facilitate negotiations between stakeholders. In order to illustrate the proposed approach, this paper compares the evaluation of a project using classical CBA and MATE through application to an example case from the transportation domain, an airport express from downtown Chicago to O'Hare International Airport.

Keywords – Tradespace Exploration, Cost-Benefit Analysis, Transportation, Project Evaluation

1 Introduction

Transportation projects deliver a complex set of costs and benefits over long periods of time and in the presence of high uncertainty (e.g., demand). A transportation project as understood in this paper is a project that encompasses the conceptual design, engineering and construction of transportation infrastructure, and is subsequently operated. In many places today the times are changing from eras of expansion to those of predominantly maintenance and operation of existing transportation infrastructure. However, in a number of areas, such as high-speed rail or integration between different modes of transportation (e.g., airport connectors), significant construction activity is still taking place.

In these cases in which new transportation structures are built and integrated with existing systems, changes in the behavior of the legacy systems occur. These behavior changes can be anticipated or unexpected, making future behavior hard to predict accurately. A pedestrian bridge, for example, may enhance the safety for non-motorized travelers but at the same time can encourage car drivers to speed, which can lead to the annoyance of residents in the neighborhood. Traffic calming measures to prevent speeding may in turn lead car drivers to discover alternate shortcuts through other neighborhoods, thereby adversely impacting those neighborhoods, and so on. This example shows the difficulty of predicting the impact certain transportation projects will have on traffic patterns. Sussman calls this kind of complexity "behavioral complexity" and defines it along with three other types of complexity that are of primary concern for CLIOS systems: structural complexity, evaluative complexity and nested complexity [1, 2]. CLIOS (systems), as defined by Sussman, is an abbreviation for complex, large-scale, interconnected, open and socio-technical (systems) [3]. He lays out how each of these characteristics is fulfilled for transportation systems. "Complexity" means that a system is composed of a group of interrelated components and subsystems, for which the degree and nature of the relationships between them is imperfectly known, with varying directionality, magnitude and time-scales of interactions [1]. "Structural complexity" refers to a system that consists of a large number of interconnected parts. "Nested complexity" is a concept that denotes that a technical system is embedded within an institutional system, which exhibits structural and behavioral complexity in its own right. "Evaluative complexity" suggests that multiple stakeholders exist for a system, who hold different views of what desirable and undesirable aspects of system performance are. Even if the behavior of systems could be predicted accurately, which it often cannot, different people will evaluate that behavior differently, making decision-making difficult.

Methods for project appraisal for transportation systems need to account for these complexities.

2 Cost-Benefit Analysis

2. 1 Characterization

Cost-Benefit Analysis (CBA) is one of the most widely accepted methods for project appraisal for large-scale infrastructure investments in the private and public sector. In the US, Government Authorities such as the Federal Aviation Administration, the National Highway Safety Administration, the Environmental Protection Agency, and the Occupational Health and Safety Administration require CBAs to be performed for a variety of projects to move forward and receive Federal funding or permits [4]. EU Cohesion Policy regulations require a CBA of all major investment projects applying for assistance from the Cohesion Funds, where major denotes projects between 10 million Euros and 50 million Euros, depending on the project class [5].

CBA seeks to enumerate all direct costs and benefits to society of a particular design, assigns them monetary equivalents, discounts future values to a Net Present Value, and adds them to a single number. Direct costs and benefits are those that are directly experienced by stakeholders of the transportation system, such as travel and waiting time, construction expenses, crash costs, and externalities such as noise or pollution. Indirect effects are those that occur to the regional economy as a whole, such as changes in rent prices, land-use patterns, or employment generation. These effects are typically considered separately from CBA in the Economic Analysis of a project. The differences in CBA scores among alternatives allow a ranking of alternatives and a reduction of feasible designs to those that would constitute Kaldor-Hicks improvements. Kaldor-Hicks efficiency is a measure for economic efficiency holding that an outcome is efficient if a Pareto optimal outcome could theoretically be reached by compensating stakeholders who are made worse-off by the outcome. For example, a voluntary trade would be Kaldor-Hicks efficient if a third party suffered externalities such as pollution, but the buyer and the seller would still be willing to carry out their trade if they had to reimburse the disadvantaged third party. It is not required that the act of compensation actually be carried out. Pareto improvements require that every participant in a trade be made better off, meaning that he must at least not be worse off after the trade. As such, Pareto efficiency is a subset of Kaldor-Hicks efficiency.

Transportation evaluation methods have been improved and become increasingly comprehensive, as larger frameworks were developed that seek to integrate different evaluation methods to give a more complete picture. The CLIOS process as described by Sussman [3] is one such example for a larger and more comprehensive framework for transportation planning that encourages the use of CBA and other methods such as stakeholder analysis at different steps throughout the process. On the other hand, CBA itself is subject to suggestions for improvements. Two examples are Wang and Liang [6], who suggest the use of fuzzy concepts in CBA, and Rivey [7] who proposes the incorporation of real options thinking into CBA if the evaluated designs allow for flexible development.

Recognizing these new developments, CBA as referred to in this paper is “classical” CBA as defined by, for instance, the Federal Highway Administration in a primer on Cost-Benefit Analysis [8]. As laid out in the FHA primer, CBA is one method of several that are typically performed in the process of project appraisal. Other important studies are a financial feasibility study, Economic Impact Analysis and Environmental Impact Analysis (in the form of an Environmental Impact Analysis or Statement).

CBA seeks to ensure that the net benefits to society are positive, but disregards the distribution of costs and benefits. Economic Impact Analysis (EIA) sheds light on likely losers and beneficiaries of a project. Methods for EIA include relatively simple qualitative methods such as surveys, market data and case studies, or more sophisticated ones such as regional economic models. In an economist’s perspective, the indirect benefits of a project as expressed in consequences to the economy in changes in rent prices or employment generation are a transfer of the direct benefits through the operation of the marketplace of a transportation project. If, for example, commuting times from a particular neighborhood decrease and living there becomes more desirable, commuters are willing to pay a higher rent. They thereby transfer part of their benefits from faster commuting times to the landlords. It is assumed that the indirect effects are not additive to the value of the direct effects measured in CBA [8]. This is the reason why CBA practice only previews the quantification of direct benefits, but not of indirect economic benefits. With ongoing research in the domain of agglomeration benefits this notion may change in the future.

The National Environmental Policy Act of 1969 (NEPA) requires the analysis of the social, economic and environmental impacts of any project that receives Federal funds or Federal approvals. EIA and Environmental Impact Analysis are typically important parts in this analysis. While NEPA requires that externalities be mitigated, the CBA is typically performed before Economic or Environmental Impact Analyses are conducted. CBA can therefore inform the later two analyses and mitigation costs can be included in the EIA, but an analysis of environmental consequences is not performed until after CBA and is typically not therein included.

2.2 Benefits and shortcomings of CBA

CBA allows a certain transparency that helps to justify political decisions and makes possible the comparison of different designs on a common scale. There are a number of flaws inherent in this method however [9, 10]. Some of these flaws are the introduction of critical value assumptions through the discounting of non-monetary goods, interpersonal utility comparisons and loss of information about the distribution of costs and benefits, and the aggregation of certain and uncertain costs on a common scale. Critical value assumptions relate, for example, to practices for the elicitation of monetary equivalents for health risks or accidents, or to the discounting of future environmental damage [11]. Heinzerling and Ackermann argue that this practice devalues the lives of future generations compared to generations today. Some practices for eliciting the monetary value of damage, such as a crash, are questionable since they assume a linear relationship between risk and willingness to pay. A person's willingness to pay to avoid a marginal risk of accident however does not need to be the same as that fraction of a person's willingness to pay to avoid a sure accident, since the utility can be non-linear. Interpersonal utility comparisons occur since costs to some parties can be balanced by benefits to another party, without assurance that any compensation of costs and benefits actually takes place.

The Federal Highway Administration (FHA) acknowledges in [8] that one source of error is the comparison of only one, or a limited number of alternatives, to the base case. In that case, the base case (minimal change) may look advantageous even though less costly alternatives exist. On the other hand, if advantageous options are left out of consideration, the analyst can (willingly or unwillingly) bias the analysis by making a suboptimal option look like the most promising one. The FHA therefore recommends that "proper" CBA should consider a "full range of reasonable alternatives" [8]. Without a systematic approach to exploring a larger number of feasible alternatives however, the risk of sub-optimizing always remains. The same problem applies to cases in which two projects are lumped together in one, yielding an overall CBA that may be positive or negative. In reality, however, one of the projects may be a good one whereas the other one should be rejected. It remains to the expertise of the analyst to ensure that separable projects not be lumped together as one in the same CBA.

Another shortcoming arises from the fact that very often in infrastructure projects different types of non-monetary "costs" have to be considered, typically in the form of externalities such as environmental impact, noise, health and safety risks. In CBA, these non-monetary costs (as opposed to monetary costs of construction and maintenance) are considered. CBA suggests that these costs can be properly characterized and compensated for. In practice, however, compensation of stakeholders cannot always be easily achieved. There are no measures like noise walls or soundproof windows to compensate for visual impairment, for instance. Monetary payments may be given to one generation of stakeholders, but will not be given to the next one. Similarly, environmental damage may be irreversible despite investments in environmental protection elsewhere.

Lastly, CBA loses information about the time-criticality of steps. A project may be more useful if it is put online before a certain event. In the example case that is discussed in this paper, the airport express would deliver more value to its stakeholders if it was completed before the Summer Olympics in 2016, should Chicago be selected as the host city. Programmatic attributes such as "project completion before 2016" cannot be included in CBA. It is possible to discount future benefits more steeply through the choice of the discount rate. That method is however a very crude way of modeling benefits since all future costs and benefits would be discounted equally steeply, regardless of their time-dependence. According to recommendations for good practices of CBA, there should not be much discretion in the choice of how costs and benefits are valued. While the monetary value of costs and benefits like reduced travel time or pollution is dependent upon local factors, agencies like the FHA, the US Department of Transportation (USDOT) and some state Departments of Transportation provide guidance about where and how to retrieve the required data to ensure comparable procedures for different projects.

3 Multi-Attribute Tradespace Exploration

This paper demonstrates the use of CBA and a second method for project evaluation in an example case. The purpose of this paper is to explore if and how the mentioned shortcomings appear in the case study, and to see if the second method, Multi-Attribute Tradespace Exploration (MATE), can be used to mitigate some of the shortcomings. In addition, this paper demonstrates how MATE, developed using aerospace examples, can be applied to the domain of transportation.

The example case is based on plans at the Chicago Transit Authority (CTA) to construct an airport express to provide a better connection between downtown Chicago and O'Hare International Airport. The evaluation in this paper is not intended to provide technical guidance in this particular project but to illustrate different methods for project appraisal. This paper also does not represent any official views or positions by any agency that is named herein.

MATE is a value-based decision and design method for the conceptual design of complex technical systems through tradespace exploration. Developed using aerospace examples, it is ultimately intended to be useful across domains. [12] and [13] provide an extensive description of the MATE process and give example applications. The goal of the method is to help create designs that provide value to its stakeholders in a changing environment and value context. The underlying idea is the use of perceived value by stakeholders as decision metrics. MATE therefore places high importance on the preferences, including those not articulated, of key decision makers. The method seeks to avoid suboptimal outcomes that are caused by settling on a single point-design early on in the design process, but rather stimulates the development of many designs and their systematic exploration. Benefits of MATE include: 1) support in the creation (not only evaluation) of designs, driven by preferences; 2) visualization and communication of complex system tradeoffs in both technical and preferential metrics; 3) opportunities for learning by key decision makers through application of the process. Tools such as tradespace exploration and network analysis allow the representation of complex data in a tractable form that allow the human mind to discover patterns, and help facilitate communication about different designs. MATE provides a framework for discovering optimal solutions in multi-decision maker tradespaces, such as those that are often encountered in the transportation domain. Decision makers learn through the MATE process about their preferences and those of others, including value tradeoffs between different attributes of a design, as well as key limiting constraints on system possibilities. The information obtained through this process may help multiple decision makers with differing interests achieve an acceptable consensus faster in negotiations.

The initial step (set-up) consists of the definition of a mission objective, and of contexts and constraints on the system. The analyst identifies a set of key decision makers. He further derives a list of attributes for each decision maker and the valuation of the attributes as obtained from structured utility interviews. *Attributes* are typically performance metrics that the decision maker values. According to change scenarios, possible future attributes are discussed and included. In the next step, system concepts are derived. A system concept is the mapping of function to form. The concept can be parameterized as a specific vector of design variables. *Design variables* are designer-controlled, tradable quantitative parameters that in their entirety characterize a specific design. The design variables are derived from the designer's expertise and knowledge as to how an attribute can be displayed by a system, which then leads to the definition of systems concepts. No concept should be ruled out at that point in the design process. The possible relationships between actual and potential attributes to design variables is brainstormed and later mapped to attributes. The mapping of design variables to attributes requires the modeling of the underlying relationships, including the cost relationship. These models can be as crude or refined as desired and feasible within the available resources. The utility for different designs can be calculated using Multi-Attribute Utility Theory [14]. The relationships nailed down within the second step are sufficient to graphically display several designs in a tradespace between two axes. Utility and cost have most often been used as these two axes in examples. In past applications in the aerospace domain, the overall utility derived from performance in the attributes was displayed against overall lifecycle cost in a tradespace.

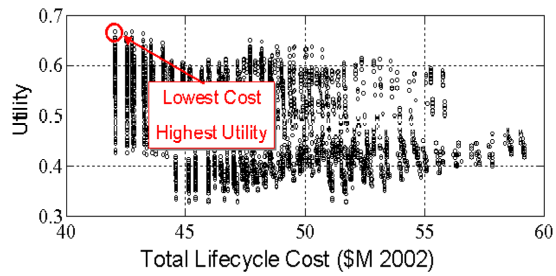

Figure 1: *Tradespace for space example (Source: Ross [15])*

The example (Figure 1) illustrates how tradespaces are read: The Pareto Front consists of designs that are available at the lowest cost for a desired level of utility. Starting with the indicated point, the Pareto Front is the upper edge of the tradespace. For applications in the transportation domain, the exploration of system design utility (often describing benefits) against *several* undesirable attributes (multiple cost types), becomes important. Those attributes that the designer wants to keep at low levels, like development time or emissions, come at "expense."

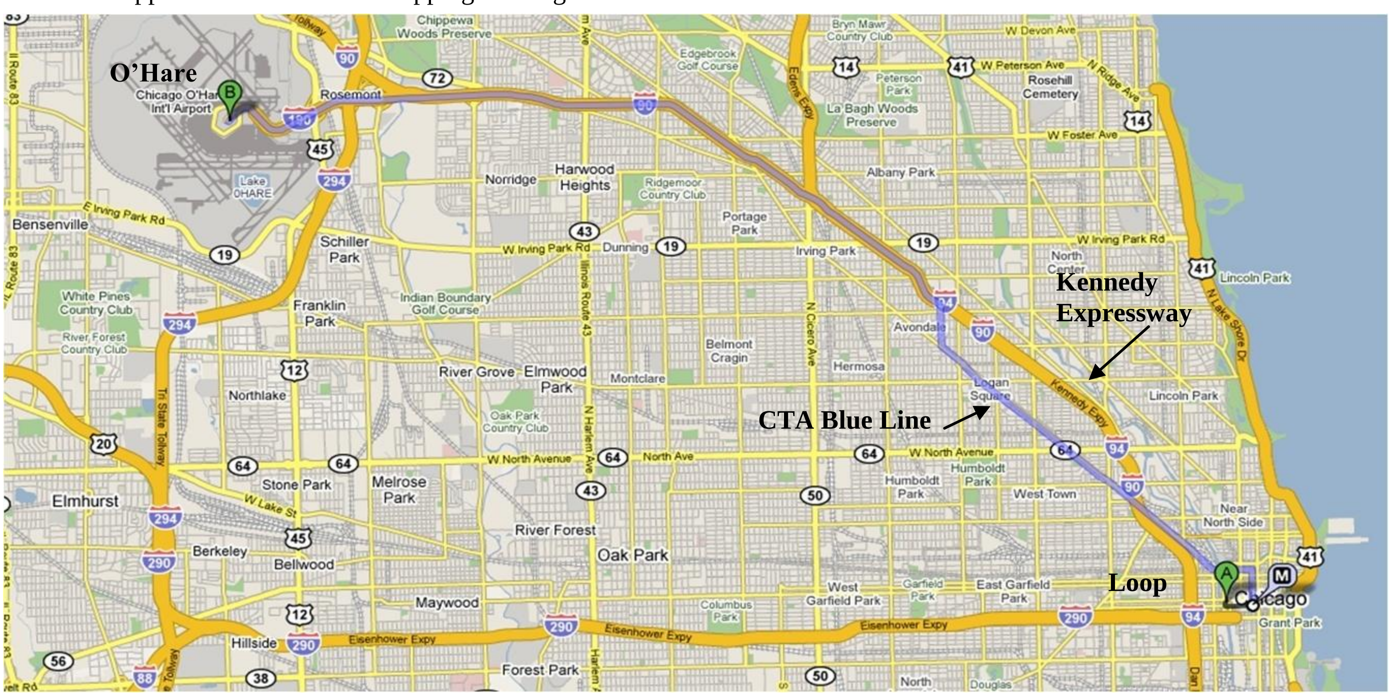

Figure 2: *Airport access via Kennedy Expressway and CTA Blue Line (Source: Google Maps)*

An expense is akin to the idea of negative utility. The idea of Single- Attribute Expense Functions was proposed by Diller in the context of space system development expenses [16]. For applications to the transportation domain, undesirable attributes that constitute "expenses" include safety risks, noise, pollution, and other externalities. The aggregation of several types of costs to a single expense function is performed in the MATE section of this paper.

4 Approach

The approach in this paper consists of 8 parts. An introduction (1), identification of stakeholders (2) and summary and their attributes (3) using both CBA and MATE, generation of alternative system concepts (4), calculation of Cost-Benefit Values for different options (5), calculation of aggregated Utility-Expense and plot of tradespaces for different design options (6), evaluation of the best alternative (7), and discussion of the shortcomings of CBA (8) that were mentioned in the beginning. The paper finishes with a summary and conclusion.

5 Case application: Chicago airport express

1) Introduction (research environment, present and past conditions, system boundary)

Chicago's main airport, O'Hare International, is currently accessible via two main routes: by road via the Kennedy Expressway, and by train via the Blue Line, a rapid transit line operated by the CTA (Figure 2). The Kennedy Expressway is one of the main arteries into Chicago and serves commuters as well as travelers to the airport. The Blue Line consists of two tracks and operates at 5-10 minute headways depending on the time of day. Both transit and individual travel are unsatisfying for airport travelers. Access to the airport by bus, hotel shuttles, taxis or car drop-off is unreliable due to the Expressway's frequent and highly variant congestion (Figure 3) [17].

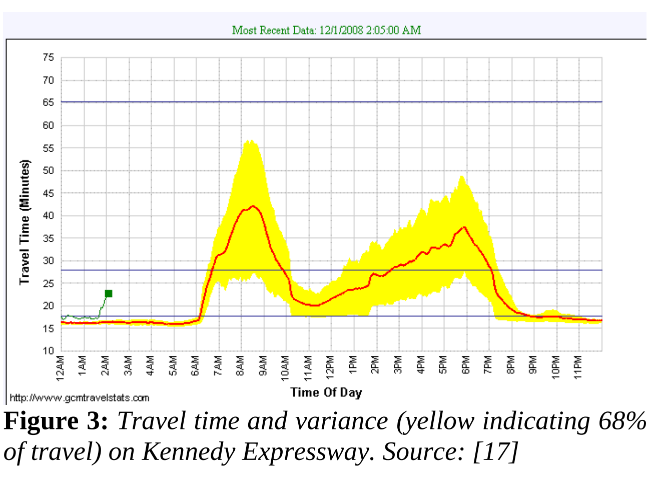

Figure 3: *Travel time and variance (yellow indicating 68% of travel) on Kennedy Expressway. Source: [17]*

Travel times range from as short as 25 minutes to over one hour for the 16-mile trip. The CTA Blue Line, on the other hand, stops 15 times on its way from the Loop (downtown Chicago) to O'Hare. The ride takes 50 minutes from downtown and is a true hike with luggage: a number of train stations are not equipped with elevators, the turnstiles are hard to pass with luggage, and the train does not provide storage space for large pieces of luggage. The planned airport express encompasses the physical connection between a dedicated downtown terminal (currently under construction) and the CTA terminal at O'Hare, the tracks and rolling stock, and existing local connections from downtown to O'Hare (the Kennedy Expressway and the CTA Blue Line).

2) Identify system needs and stakeholder groups

To ensure Chicago's competitiveness with other global cities for conferences and business, the CTA and Planners at the Mayor's Office realized the need for a fast and reliable airport connection. The stated goal of the proposed project therefore is to improve access from downtown Chicago to O'Hare. The main decision making stakeholders are those that are expected to contribute to the funding of the airport express: the City of Chicago, the CTA, and a Private Operator. In addition, the affected public and travelers to the airport have a stake but no formal decision making power. Although application for federal grants is an option once a decision for a design has been made, a preference for a design that could be self-financed is assumed in case no additional funding becomes available.
The *City of Chicago* hopes to sustain economic growth in the downtown area and to ensure Chicago's competitiveness with other world cities for business and conferences. The *CTA* as the operator of Chicago's public transportation system would be closely integrated in the construction and operation of the proposed airport express. Due to scale effects and expertise, operation and maintenance of the airport express would be outsourced to the CTA. The vision for the airport express is that of a premium service that would charge a premium fare. Since the CTA does not have experience with running a premium service, a private sector concessionaire (*Private Operator*) was suggested to be charged with the management of the airport express [18]. The hope is to leverage business knowledge from the private sector, secure a contribution to the project funding through availability payments, and help establish a new premium brand name.

Other stakeholders without formal decision making power are *passengers to O'Hare*, segmented in *business* and *leisure*, *residents adjacent to tracks*, and the *greater Chicago public* (the "taxpayer"). *O'Hare International Airport* and to a lesser degree some *airlines* are further stakeholders. O'Hare and airlines have been excluded from the City's technical studies with no reason given. It appears that the planners at the Mayor's office and the CTA do not count on funding from the airport and therefore do not pay them much attention. An agreement with O'Hare is mentioned stating that the CTA may modify its O'Hare terminal to accommodate an airport express [19].

3) Identify attributes of interest (both costs and benefits) to each stakeholder or stakeholder group

Two methods were used to identify attributes of interest. In MATE, an attribute denotes any cost or benefit, tangible or intangible, that a stakeholder cares about. The list of attributes in Figure 4 was elicited in interviews with proxy representatives from the three main stakeholding agencies City of Chicago, CTA and Private Operator. A consultant from Parsons Brinckerhoff who had been involved in the preparation of a business plan for the airport express in 2006 assumed the role of the Private Operator.

Rank	City of Chicago
1	Estimated tax base change
2	Generation of Employment (tied with 1)
3	Availability of outside project funding (tied with 1)
4	Attraction of visitors to downtown Chicago
5	Equity (spending on other projects) (tied with 4)
6	Estimated out-of –town visitors
7	Travel time compared to existing
8	Reliability of trains (tied with 7)
9	Attraction of businesses to downtown(tied with 7)
10	Initial public support (tied with 7)
11	Confidence in final project cost (tied with 7)
12	Confidence in final project schedule (tied with 7)

CTA	Private Operator
Up front investment required from CTA	Return on investment, pre-tax
Impact on current operations - overall capacity	Little competition from CTA Blue Line and road investments
- probability of recurring delays to existing trains (tied with 2)	Autonomy in operation (e.g. fare increases, operaiton) (tied with 2)
Maintainability	Concession payment
Degree of certainty in final project cost	Growth of operating costs
Survivability- prevention of breakdowns	Construction schedule (length)
Survivability- recovery (tied with 5)	Fare growth and fare price in year 0
Little dispersion of control (tied with 7)	Ridership growth and level in year 0
Market share (tied with 7)	
Length of concession contract (tied with 7)	

Figure 4: *List of attributes elicited from stakeholder interviews*

In CBA, several guidelines suggest typical costs and benefits that should be considered in a project. The FHA primer [8] and guidelines on the website of the California Department of Transportation [20] were used to define costs and benefits for the airport express project (Figure 6).

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	

Figure 5: *Relevant costs and benefits of Airport Express options*

The FHA primer states that changes in operating costs for vehicles tend to constitute a minor share of the benefits of a project. This benefit was therefore not considered in the calculation. Reduction in crash rates were equally a less important consideration than other costs and benefits and were omitted.

The lists in Figures 4 and 5 illustrate that the costs and benefits for CBA are different from those that are elicited from stakeholders in the interviews. Stakeholders in the interviews expressed a more agency-focused point of view pertaining to their respective organizations. This bias is expected and permitted when eliciting attributes for MATE, since attributes can be anything that a stakeholder cares about, whether it can be monetized or not. Costs and benefits, on the other hand, have to satisfy a strict set of rules about what are and are not permissible attributes for a CBA. All attributes for a CBA could be attributes in MATE, if so expressed by a stakeholder, but not the other way around. As it turns out, the attributes elicited through both methods are quite different. Attributes like congestion relief or emissions do not appear very prominently on the lists of the interviewed stakeholders. In general, much of their attention focuses on second-order effects to the economy. Since no stakeholder in the main decision making set expressed strong advocacy for the environment, a proxy stakeholder can be introduced for a more comprehensive analysis. The proxy stakeholder for the environment can be thought of as a representative for unarticulated attributes. It is assumed that environmental preservation and externalities are unarticulated values for the main decision makers since it is unreasonable to assume that the levels of externalities could be increased infinitely without the decision-making stakeholders eventually caring. The fact that stakeholders did not express these attributes in their lists of top attributes either means that they did not want to prioritize them or that they did not occur to them as important during the interview.

4) Generate alternative system concepts (mode choice and corridor)

Since the first airport access improvement study in 1999, a rail solution was the only design option that was seriously considered [18]. As expressed in an interview with a CTA representative, Bus Rapid Transit (BRT) was ruled out because of prestige concerns that might fail to attract the targeted premium audience. In order to prevent a suboptimal decision, BRT is included in the four design alternatives that are compared to the base case (minimal change).

Direct Service (Route 1)

Route 1 would utilize the existing Chicago Transit O'Hare Blue Line tracks between O'Hare and the new downtown terminal. The non-stop airport train (running time 29 minutes) would need to overtake the local train (running time 50 minutes) on two bypasses, since only one track per direction exists. This operation would effectively restrict reliability of the airport express to that of the local train, since the airport express would need to wait in the bypasses for delayed "meet" trains (Figure 6).

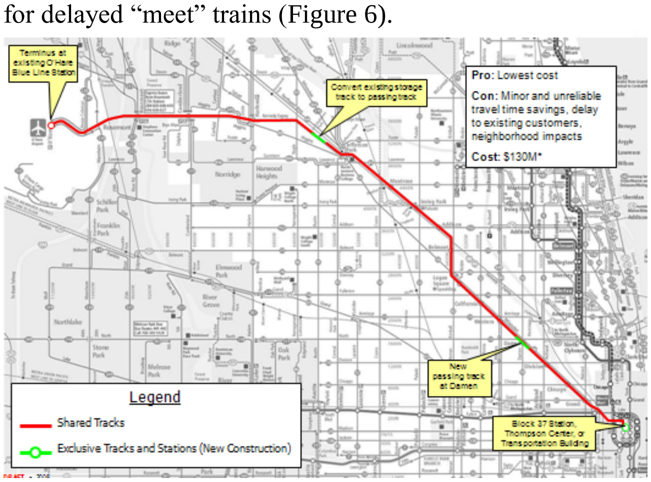

Figure 6: *Direct service. Source: CTA*

Express Service (Route 2)

The express service would operate on its own dedicated right-of-way, using an unused suburban rail line (Figure 7) containing three tracks on a four-track right-of-way. Rebuilding an originally planned, but abandoned, fourth track would allow simultaneous operations of the suburban rail and the airport express if such operations should be desired in the future.

Figure 7: *Express service. Source: CTA*

Bus Rapid Transit

To ensure the required reliability, BRT can realistically only be operated on a dedicated lane along the Kennedy Expressway. There are currently five lanes (Figure 8). An important question to answer is whether enough traffic can be relieved from the Expressway to offset the reduction in capacity. Capital costs are minor, since only two new bus terminals would need to be built.

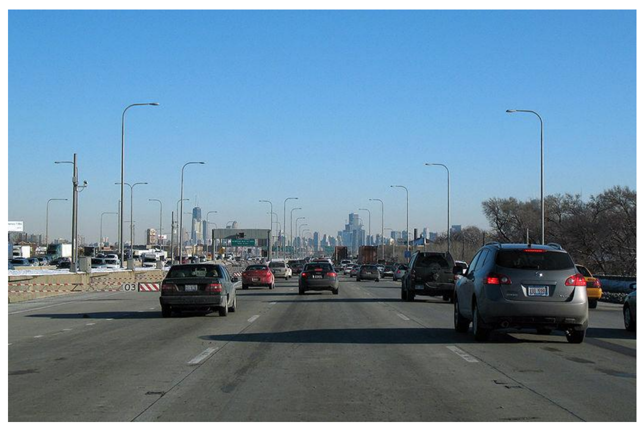

Figure 8: *Kennedy Expressway. Source: Wikipedia*

Blue Line Switch

In this option, the Blue Line Rapid Transit connection would be made a BRT connection, operating on its own dedicated lane on the Kennedy Expressway. The freed up Blue Line tracks would be used for the airport express. Since BRT buses fit fewer passengers than Rapid Transit cars, headways and consequently waiting time would be improved for users of the local service.

5) Calculate aggregate Cost-Benefit (CBA)

The focus in the CBA is on changes in travel time, emissions, capital and operating cost. Noise to residents and adverse neighborhood impacts from construction are qualitatively acknowledged but not quantified for reasons of scope and lack of data. They are the kind of effects that would typically be discussed in an Environmental Impact Statement along with requisites to mitigate those effects. Since the projects require construction costs in the area of several hundred millions of dollars, compensation methods would not change the order of magnitude of the project costs. Delays to Blue Line riders are not quantified since these would only occur in the case of Direct Service. In the stakeholder interviews the City of Chicago expressed that a reliability of less than 80% was not acceptable for the airport express. As it turns out in the analysis, Route 1 does not meet the required reliability requirement and is therefore not a feasible option. Specifically, CTA studies suggest that Direct Service can only achieve reliability of 70%, as measured in trains that are delayed for more than a certain percentage of headway, due to the coupling of reliability to the reliability of the local trains. Route 1 is therefore not acceptable.

Figure 9 shows the outcome of the CBA for the airport express options. All benefits and costs are calculated relative to the base case, which therefore by definition is 0.

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

Figure 9: *Quantified costs and benefits of feasible Airport Express options*

Negative numbers constitute savings to society, whereas positive numbers constitute increased costs. BRT is beneficial independent of the discount rate between 7 and 10%. Route 2 has high initial costs and provides benefits later on. Savings to society are therefore favored by a lower discount rate. The Blue Line Switch Option (BLS) does not provide any net benefits to society according to this analysis.

The CBA for all options has three components: monetary costs (construction, vehicle acquisition, operating cost and vehicle replacement), emission increases or reductions, and travel time savings to airport travelers, car drivers and Blue Line riders.

Construction, vehicle and operating costs
Route 1 is left out of the following calculations (Figure 10, Figure 11) since it is not a feasible option.

	Vehicle cost	Capital Cost	# vehicles required		Travel time	Sched rel
	(in mn 2008$)		Train cars	BRT	min	% on time
Route 1	50.4	130	28	0	29	70
Route 2	50.4	480	28	0	25	98
BRT	5.6	2.5	0	7	25	90
BLS	147.4	10	28	121	25	99

Figure 10: *Basic cost and performance data for airport express options*

BLS-all in Figure 11 includes the cost of the new operations without subtracting the savings from not operating the Blue Line anymore. BLS excluding former Blue Line corrects for that mistake and is appropriate for comparison with the other options.

(in mn 2008$)	Av. Operating cost $/day		
	Fuel	Personnel-operations	Personnel-maintenance
Route 2	2,112	1,856	5,568
BRT	2,870	2,784	2,784
BLS -all	32,131	6,960	20,880
BLS- excl. former Blue Line	2,558	1,856	5,568

Figure 11: *Operating costs for feasible airport express options*

Emission increases or reductions
Using an emissions model by the California Department of Transportation [20], the following values for emission impacts for the different options were calculated (Figure 14). The increases or decreases in emission costs relative to the base case are included in the CBA. The monetary numbers of the adverse health effects from increased emissions are calibrated for rural California, and need to be treated with some caution. The colder climate and urban environment in Chicago may result in changes to those values, which should be kept in mind in a study to inform decision making. The percentages of cars at different average speeds on the Kennedy Expressway were obtained from GMC traffic counts [17].

Changes in travel times and delays
Travel time savings (Figures 12, 13) were calculated using traffic data about the Kennedy Expressway [17], CTA traffic counts [21], and ridership estimates from a business plan about the airport express [18]. The volume-speed relationship on the Kennedy Expressway was based on the volume-speed diagram in [22]. Information about average wages to determine the monetary value of time savings was obtained from the US Department of Labor [23].

Travel time savings	Airport travelers	Car travelers	Blue Line riders
(min/day)			
Route 2	62,450	97,362	0
BRT	62,450	0	0
BL switch	62,450	0	261,000

Figure 12: *Travel time savings in minutes to different stakeholder groups*

Travel time savings	Airport travelers	Car travelers	Blue Line riders
($/day)			
Route 2	15,613	16,227	0
BRT	15,613	0	0
BL switch	15,613	0	43,500

Figure 13: *Monetary value of travel time savings based on average wages*

	CO	NO_X	PM_{10}	SO_X	VOC
Route 2	(g/day)				
g/day	21,975,252	6,826,416	587,768	11,616	2,116,929
$/day	1,253	72,763	48,557	485	1,666
Sum $/day	124,723				
BRT					
g/day	21,974,047	5,730,617	463,785	12,490	2,085,937
$/day	1,253	61,083	38,314	521	1,642
Sum $/day	102,812				
BL Switch					
Sum g/day	22,479,632	3,842,909	237,562	15,281	2,089,108
$/day	1,281	40,962	19,625	638	1,644
Sum $/day	64,150				
Baseline					
Sum	22,417,298	5,699,453	464,594	11,903	2,125,473
$/day	1,278	60,750	38,381	497	1,673
Sum $/day	102,579				

Figure 14: *Emission costs for different airport express options*

The cars on the Kennedy Expressway are the main producer of CO-emissions. This is the reason why the values for CO are similar across different options.

6) Calculate aggregate Utility-Expense, plot tradespace (MATE)

The attributes elicited in the stakeholder interviews (Figure 4) give a sense of the interests of different stakeholders. Many of the attributes that were expressed in response to the question “What would you value about the airport express?” are higher level political or strategic attributes such as employment generation or Return on Investment. It is easy to see how these attributes constitute a desirable measure for success from the side of the stakeholders. They depend however on a variety of influences that are only partially under the control of the designer who develops the airport express. Employment generation in the hotel industry in downtown Chicago depends on the visitors to Chicago. Visitors to Chicago, especially those attracted by business purposes, certainly value a reliable method to get to downtown. The number of such visitors however depends also and even more strongly on Chicago’s general attractiveness, of which the airport express is only a small part. Generation of employment, or even generation of ridership, are therefore not “fair” measures for success in the sense that the contribution of the airport express is not adequately reflected in these measures. To operationalize the attributes that stakeholders expressed, complex attributes were decomposed down to the underlying factors that influence them (Figure 15). Tradespaces were plotted for the three decision-making stakeholders: City of Chicago, CTA and Private Operator. It is important, however, to appreciate what other stakeholders care about, such as the public or the future users of the airport express, since their utility is factored into the utility of the decision making stakeholders. The attribute “Public support” of the City of Chicago reflects, for example, the concern for approval by the general public in Chicago. Whether the users or the public receive the level of attention by the decision-making stakeholders that may be desirable is a different question. It doesn’t change the fact however that, just as in reality, the influence of non-decision-making stakeholders is indirect and their concerns are (hopefully) reflected in the priorities of their representatives. This is the reason why only the decision-making stakeholders are considered for the following MATE analysis.

Of the larger list, in order to simplify the case study for demonstration purposes, only the top four attributes were considered for the CTA and the Private Operator. According to the weighting expressed in the interviews, this captures 70% and 80% respectively of the weight the interviewees put on all attributes they enumerated. In the case of the City of Chicago, the weights were more equally distributed over the enumerated attributes, and the fourth and fifth attributes were tied. Therefore the top five attributes were considered in the case of the City of Chicago, accounting for 56% of the City’s distributed weight.

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		

Figure 15: *Underlying factors for Chicago's attributes*

Figure 15 shows the decomposing of underlying influences for the attributes that were expressed for the City of Chicago. It emerges that the controllable driving factors are: 1) the attractiveness of the airport express to riders, 2) initial costs (construction and vehicle costs), and 3) the share of the initial investment that the City must bear. Land value and ridership depend on several factors, of which ultimately attractiveness of the airport express is the one that the designer can influence. Attractiveness is addressed in the following case by the attribute "Quality of Service" (QOS) for the airport express.

QOS measures essentially how well the stakeholder group "airport express users" is catered to. Different users will answer this question differently. A business traveler may prioritize reliability and travel time, whereas a leisure traveler or somebody who picks a traveler up from the airport will care more about a low price. The City's initial cost, the city's cost share and QOS are the operational attributes, derived from the high-level political attributes expressed in the interview (Figure 16). The ranges and measures are based on information from stakeholder interviews wherever applicable. Desirable attributes provide utility (u); undesirable attributes constitute expenses (e). Below a utility level of u=0 or above an expense level of e=1 a stakeholder refuses his stake and abandons a project. Qualitative attributes such as QOS are measured on a scale of 0 to 5, where 0 denotes the lowest level of service and 5 the highest.

Attributes	Measure	Min acc e=1	Max acc e=0	Weight
City's initial cost	mn$	640	100	0.16
City's cost share	%	50%	10%	0.12
		u=0	**u=1**	
QOS	Scale [1 to 5]	2	5	0.28

Figure 16: *Attributes and ranges for City of Chicago*

A market segmentation of airport express riders is a possible refinement to the analysis conducted. Since it is not necessary for the demonstrative purpose of this example, airport express users are treated as a single group in this paper.

DVs	Range	Measure
Concept	[1, 2, 3]	Route 2, BRT, BLS
Fare level	[5, 20]	$
Frequency	[5, 20]	headway in min
Travel time	[20, 30]	min
Amenities	[1,2,3,4,5]	Scale
Span of service	[16, 24]	hr/day
Cost share City	[0.10, 0.50]	%

Figure 17: *Design variables for City of Chicago*

The list of design variables was generated based on the analyst's knowledge about drivers of different attributes (Figure 17).

Figure 18 shows a mapping of attributes to design variables. A score of 9 indicates that the attribute is driven strongly by the respective design variable, 3 indicates a medium influence, and 0 indicates no influence. The actual model was based on the relationships as represented in Figure 18. In the case of the City of Chicago, the attribute "City's cost share" can be directly controlled. It is therefore both an attribute and a design variable.

	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

Figure 18: *Attributes and design variables for the City of Chicago*

Reliability and accessibility were not considered in the attributes, despite their importance for QOS. The reason is that the factors that drive reliability appear to be largely concept-independent and are therefore excluded for now from the analysis. A concept is the decision for either a separate train (Route 2), BRT, or the Blue Line Switch option. Reliability can be improved through improved maintenance and training and monitoring of staff (especially operators), but these measures are independent of the system design that is evaluated. Accessibility denotes the ease with which a user can access the downtown station. Since the downtown station is already under construction, decision makers are already "locked in" with performance in this attribute, therefore it does not vary between concepts and hence does not impact the analysis. The calculation of the QOS was equally based on the variables fare level, frequency of service, travel time, amenities and span of service (hours of service per day) - the cost for improvements in each area however differs. "Amenities" ranks the availability of features within the airport express bus or train, such as laptop outlets or screens with flight information, on a scale from 1 to 5. The design factor "travel time" can be thought of as investments for speed enhancement in vehicles. The purchase of vehicles and construction expenses constitute the initial costs for the stakeholders.

Figure 19 shows the tradespace for the City of Chicago. Utility is aggregated through a utility function on the y-axis in the following tradespaces, whereas aggregated expense is displayed on x- axis.

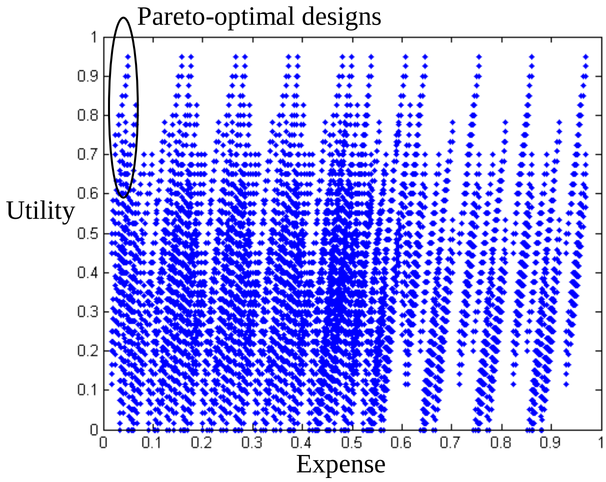

Figure 19: *City of Chicago Tradespace. Expense vs. Utility*

The tradespaces for the individual concepts are the following (Figure 20, 21, 22).

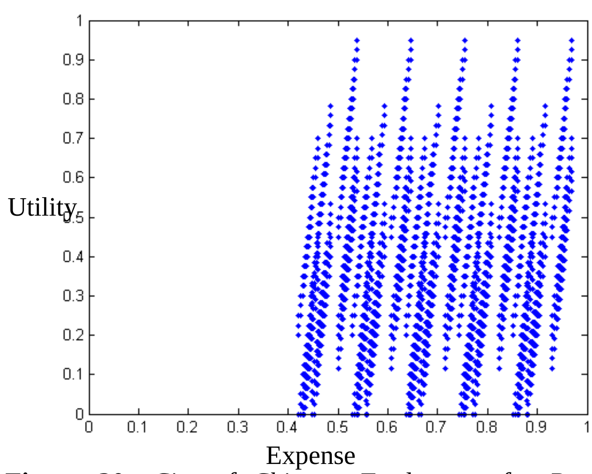

Figure 20: *City of Chicago Tradespace for Route 2. Expense vs. Utility*

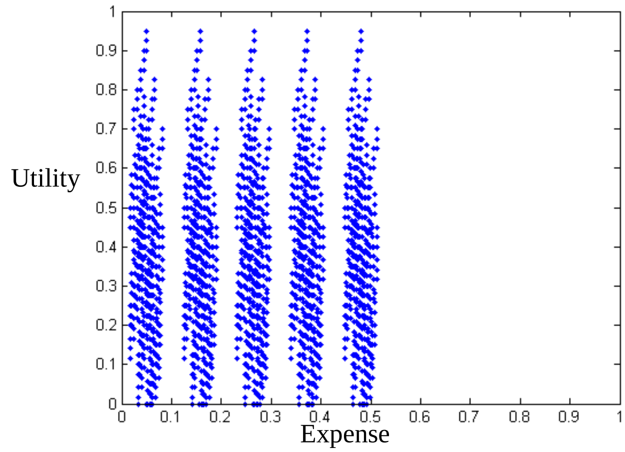

Figure 21: *City of Chicago Tradespace for BRT. Expense vs. Utility*

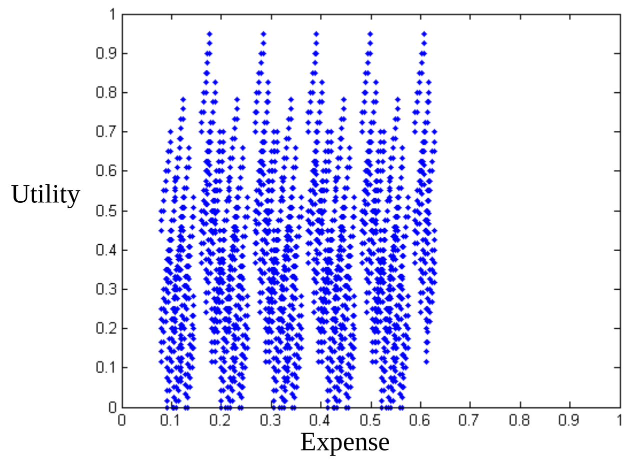

Figure 22: *City of Chicago Tradespace for BLS. Expense vs. Utility*

For the City of Chicago, QOS was the only beneficial attribute and therefore converted directly into utility. The City's cost share and the initial cost incurred by the City are both expenses and therefore aggregated on the x- axis. The difference between these two attributes is that the City has a value proposition not only for how much money it spends, but also for how much money it can attract through local matching from other sources. The value propositions for the absolute monetary contribution and the percentage share of total cost of this contribution are therefore different.

Figure 19 shows the tradespace for the City of Chicago for all concepts. The designs that provide high utility at low or no cost in the upper left corner may surprise (indicated by the circle). The reason why this is possible is that, for once, the City participates only in the initial investment, which is the financing of vehicles and construction cost. It does not finance operating expenditures. That means that preferences over higher frequency or longer span of service do not constitute an expense to the City. Second, the cost share for the City is a contractual parameter. It is theoretically possible that the City does not contribute more than 10% (which it desires to contribute in any case), thus benefitting from the system without paying much for it. The five discrete steps that can be seen in the tradespaces for the individual concepts relate to different levels of cost share (10% to 50% in 10% steps). The City has the particular feature that the operational design variables span of service and (lower) fare level provide increased utility, without coming at cost to the City. All optimal designs therefore maximize span of service (24 hour operations) and minimize fares (5$). The City is interested in a large number of riders, and therefore receives higher utility from lower fares. Route 2 is the most expensive design for the City, since it comes at the highest initial expense. BRT is the cheapest option, and BLS is relatively cheap but more expensive than BRT. The optimal designs for the City of Chicago are therefore those BRT designs that have a maximal span of service and a minimal fare. In addition, the City has steep utility increases at relatively flat expense increases. The reason is that the City only bears the cost for additional required vehicles for frequency increases, which is a relatively small part of the cost of higher frequency. The major part of the cost comes from the increased operating cost, which does not impact the City. It is important to keep in mind that the City tradespace is one tradespace within a multi-stakeholder problem space. A stakeholder can only choose a design in coordination with other stakeholders. A design that is very beneficial for, for instance, the City of Chicago because it requires little financial contribution will require a larger contribution from other stakeholders. The very beneficial outcomes for the City (high level of service, minimal financial contribution) will likely not be chosen in an actual negotiation setting with a (somewhat) balanced power distribution.

Figure 23 shows the attributes of the next stakeholder, the 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		

Figure 23: *Underlying factors for CTA attributes*

A major concern at the CTA is to not inconvenience current (local service) Blue Line riders through joint operation of the Blue Line and the airport express on common tracks. Since the only design in which this condition would have appeared is Route 1, which has already been ruled out for reasons of insufficient performance, the attribute "Shared Tracks with Blue Line" does not need to be considered anymore. Two attributes remain: the CTA's initial cost and the span of service. These two attributes include one benefit (maintainability, which is the opposite of service span or the number of hours during which tracks could be maintained), and one cost (CTA initial cost).

Attributes	Measure	Min acc e=1	Max acc e=0	Weight
CTA initial cost	$/day	100	0	0.2
		u=0	**u=1**	
Span of service	Hrs/day	24	18	0.1

Figure 24: *Attributes and ranges for CTA*

Since these two attributes can be directly influenced by the design, they are the corresponding design variables as well, as expressed in Figure 25.

DVs	Range	Measure
Up front investment req from CTA	[0, 100]	mn$
Span of service	[16, 24]	hrs/day

Figure 25: *CTA Design variables and ranges*

Figure 26 shows the tradespace for the CTA. Due to only two considered variables, the tradespace is very simple. The utility corresponds to the number of hours that would be available for maintenance per day. Every additional hour increases the utility (discretely in this model), whereas the expense (or disutility) increases depending on the required initial cost contributed to construction by the CTA. Both attributes are independent of each other. The Pareto Set for the CTA are the three designs with the vectors (0, 16), (0, 17) and (0, 18). The CTA has the highest utility if it does not need to contribute to the initial costs, and if it has at least 6 hours without operations available per day in which maintenance can be performed.

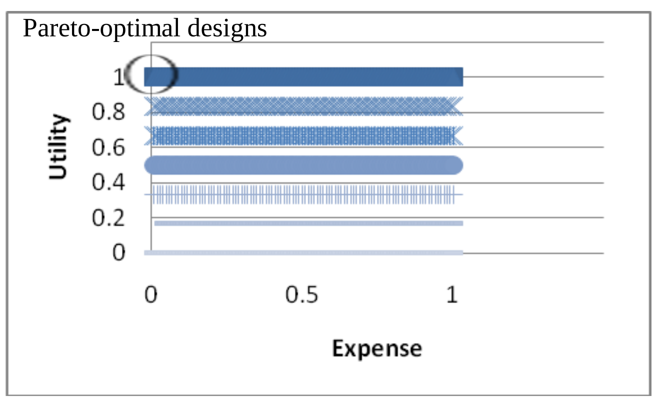

Figure 26: *CTA Tradespace. Expense vs. Utility*

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*
0.8		

Figure 27: *Underlying factors for Private Operator attributes*

Analogously to the tradespace generation for the City of Chicago, Figures 27- 31 provide information about the tradespace generation for the Private Operator. Competition agreements with the CTA and the City of Chicago limit the ability of those two to improve road capacity or Blue Line service, thereby limiting competition with the airport express.

Attributes	Measure	Min acc e=1	Max e=0	Weight
Operating costs	$/day	10,000	0	0.1
Concession payment	mn $	300	0	0.2
		u=0	**u=1**	
QOS	Scale	2	5	0.2
Freedom to make changes	Scale	1	4	0.15
Compete. Agreements	Scale	3	5	0.15

Figure 28: *Attributes and Ranges for the Private Operator*

Design variables	Range	Measure
Choice of concept	[1,2,3]	Route 2, BRT, BL Switch
Fare level	[10, 35]	$
Frequency	[5, 20]	headway in min
Travel time	[20, 30]	min
Amenities	[1,2,3,4,5]	Scale
Span of service	[16, 24]	hr/day
Freedom to make changes	[1, 5]	Scale
Competition agreement, ab to raise fares	[2, 5]	Scale

Figure 29: *Design variables for the 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

Figure 30: *Attributes and design variables for the Private Operator*

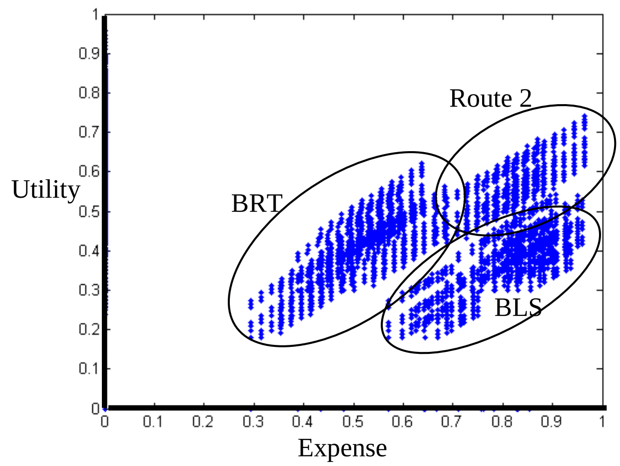

Figure 31: *Private Operator Tradespace. Expense vs. Utility*

"Freedom" refers to the attribute that permits the Private Operator by contract to make operational changes without having to consult the CTA and City of Chicago.

7) Determine "best" alternatives

The results of the CBA indicate that BRT is the only solution that provides net benefits to society independent of the discount rate. Route 2 has the highest net benefits at a discount rate of 7%, indicating that there are higher initial expenses and larger future benefits. Depending on how strongly future benefits are discounted, this option proves either advantageous or not advantageous. The Blue Line Switch option is inferior independent of discount rate. If a low government discount rate is used, both BRT and Route 2 can be justified with a CBA. CBA is however only one method in a suite of methods that are used to explore the impacts of a technical design. The decision also needs to be informed by financial analysis. BRT is a recommendable solution if one wants to ensure net benefits according to CBA that is robust against changes in the discount rate.

Attributes

In the tradespace analysis, BRT emerges as the best option for the Private Operator until a utility of approximately 0.6. Subsequently, Route 2 is the best option in terms of utility for expense. BLS is able to provide an equally high utility as BRT but at higher expense, or a lower utility as Route 2 but at similar expense. The tradespace of the CTA is not particularly helpful in selecting a design, since both attributes are independent of each other. The tradespace fits into the overall image that the CTA conveyed during the interviews: the CTA will most likely not have any financial gain from the airport express, but be merely the contractor that maintains the tracks and operates the trains in return for a contractually fixed payment. As such, the CTA is trying to minimize potential disadvantages to current operations and to their financial ability. None of the CTA attributes indicate a preference for a particular design, except that it not be Route 1 (which had been eliminated).

The preferences of the City of Chicago are driven by low initial costs, since the City would only need to bear a share of the initial expenditure. This leads to a preference of BRT over the other designs. The City also favors more frequent and longer operations (longer span of service), since those operations provide benefits which the City would not need to pay. Apart from those fundamental patterns, utility increases with increased investments in service design variables.

Overall, there is no clear dominant design that emerges from both analyses. BRT and Route 2 both have their merits, the one being cheaper (BRT) and the other providing higher utility and higher benefits later in the lifecycle. The Blue Line Switch Option is dominated in both analyses, however.

8) Discussion and evaluation of “shortcomings”

One criticism of CBA is the fact that it performs inter-personal utility comparisons, that is, it aggregates the utility of different stakeholders to a single number. In this example, CBA demonstrated that the airport express has potential to save a substantial amount of travel time for users of the airport express and car drivers on the Kennedy Expressway through relieved congestion. The inner dynamics of interests between different decision-making stakeholders however remain hidden. Even though Economic Impact Analysis as an additional method tends to shed more light on the distribution of costs and benefits through revelation of likely gains in travel time, land value, visitors, for example, of certain areas, this analysis does not apply to the personal interests of involved decision-making stakeholders.

In fact, even this example analysis for demonstrative purposes has already revealed several patterns of preferences and interests that will be most interesting for all stakeholders in actual negotiations. The CTA has not much to gain and tries to cut their losses. The City is in a situation in which it is only responsible for contributing to the initial investment, but not to operating expenses (this prediction assumes operating self-sufficiency, as is the result from several studies under conservative estimates). This political and regulatory fact has a major influence on design selection, independent of technical considerations. The Private Operator is less interested in the public good and more in Return on Investment. Whereas the City values the number of riders attracted to downtown, with the price they are paying on the airport express being a lesser concern, the Private Operator cares about profit maximization. Interestingly, the Private Operator cares about a number of attributes that do not have a monetary equivalent, such as freedom to make operative changes without consulting other stakeholders or competition agreements. These attributes were not expressed by the CTA or the City of Chicago. Depending on their preferences when these points are brought up in discussion, there may be a possibility to trade in a higher concession contribution by the Private Operator in return for concessions on these non-monetary attributes. It is questionable if and to what extent these details would have been revealed in a traditional project evaluation process. By revealing this information, MATE can constitute a valuable additional tool in project evaluation to help mitigate the ignorance of the distribution of costs and benefits and add consideration for non-monetary costs and benefits. In this way, MATE contributes to better accounting for the hard-to-come by “evaluative complexity” in project appraisal, which ultimately has to be resolved in negotiations.

Even though CBA showed that travel time savings can be substantial through the proposed project, the evaluation is skewed through the practice of discounting these non-monetary benefits. Whereas discounting makes sense for financial assets, the equivalent logic does not easily apply to the discounting of future travel time savings or future emissions. Even if the quantification into monetary values can be justified, it is hard to justify why the time of people today should be more valuable than the time of their children. The project evaluation of the option Route 2 shows how much power the discount rate has over making the same project either look beneficial or undesirable, solely based on how steeply future benefits are discounted.

In addition, several non-monetary costs such as emissions are quantified through a linear model in this paper. In reality however, there may be certain thresholds above which pollution becomes a lot worse or thresholds below which certain levels of pollution have a less severe impact. MATE allows for the accounting of this type of information, which may be gathered from experts during the evaluation process. There is a danger that certain types of “soft” benefits, such as diffuse benefits to the community or environmental harm/benefits are not perceived as urgent causes by decision making stakeholders. In this case, it is possible to capture potential unarticulated attributes either through a proxy stakeholder (“environmental stakeholder”) or in the form of unarticulated attributes.

The flexibility in capturing attributes, things that people care about, permits accounting for programmatic attributes. In this paper, the compared designs had relatively short project completion schedules of about 2 years after start of construction. Other designs for the construction of new rail tracks that were discussed in technical reports (and deemed inferior to Route 2) however, involved more construction work and a longer project completion phase. In evaluating these designs, an attribute for the likelihood of project completion before a certain deadline (e.g., 2016 for the Summer Olympics) can be introduced. Due to the selected designs, however, this shortcoming was of lesser concern in the demonstrated analysis in this paper.

Another critique of CBA is the fact that initial investments and operating costs (often far into the future) are discounted and aggregated to a common value. The case can be made that (relatively) certain expenses today and uncertain future costs or revenues tomorrow constitute different “colors of money.” This paper demonstrated how MATE can account for different cost types. In the case of the Private Operator, operating costs and construction costs were kept separate and evaluated differently (with a stronger focus on construction costs, since this attribute affected two attributes that were expressed in the interview, whereas operating expenses affected only one). Even though it was not demonstrated in this paper, it is possible to separate the costs and display them individually against the aggregate utility of different designs. This possibility for further exploration of the impact of different costs (including different “colors of money” and non-monetary costs) is another potential for additional insight that can be gained through the use of MATE.

Conclusion

The paper demonstrated the evaluation of an airport express for the City of Chicago using two different methods: Cost-Benefit Analysis and Multi-Attribute Tradespace Exploration (MATE). Developed in the aerospace domain, this paper demonstrated how MATE can be used in a multi-stakeholder problem space in the new domain of transportation. The paper further demonstrated the accounting for different cost types in MATE through the use of an expense function (akin to the idea of a “negative” utility function). A number of shortcomings of CBA appeared in the case study in this paper. MATE has the potential to mitigate some of these shortcomings, specifically through the ability to consider the distribution of costs and benefits among stakeholders, the flexibility to accounting for intangible attributes, non-linear utility of attributes and non-obvious interest patterns among stakeholders to facilitate negotiations, and the possibility to analyze different types of costs without the need to add them to a single number or to discount them.

The paper further shows how CBA can feed into MATE and how both methods can be used simultaneously to jointly inform decision making about complex designs. It is understood that CBA is not a stand-alone method, but one in a suite of techniques that is frequently employed, together with financial analysis, Economic Impact Analysis, and others. As a high-level method for the conceptual design of systems, MATE is intended to provide high-level architectural guidance and feed into more detailed planning steps of construction, operation and contract design.

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