Trading political feasibility and technical optimality: Multi-Attribute Tradespace Exploration as communication tool in transportation planning

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Abstract

A challenge in the planning of large-scale socio-technical systems is the explicit consideration of both political implementation concerns and technical properties of design concepts. Often those two dimensions are interrelated. This paper demonstrates a disconnect in a public transportation case study between political feasibility and technical optimality from a cost-performance point of view. Object of the case study is the design of an airport express, based on plans regarding access to O'Hare International Airport in Chicago. Based on the application of Multi-Attribute Tradespace Exploration (MATE) to this case study, a value-centric design and evaluation method developed in the aerospace domain, the cost of ruling out certain designs early on in conceptual design is demonstrated visually through tradespaces. The modeling effort behind the MATE study is based on technical studies by the Chicago Transit Authority and interviews with decision-making stakeholders in Chicago. Suggestions for how to modify political feasibility show that this factor can be influenced and should not cause design concepts to be ruled out at an early point in the conceptual design phase. The use of MATE as analytic tool and visual aid for communication between policy makers and transportation planners/engineers is demonstrated.

1. Introduction

Traditional engineering decision making on the one hand and political decision making on the other are very different. Engineering seeks to modify nature and to create systems that fulfill a decision maker's goals. A decision maker's goals are based on his values, tha tis on what he finds desirable and important. The *rational planning method* underlies the traditional engineering decision making process and comprises at least five steps: 1. Goal elicitation, 2. Selection of evaluation criteria, 3. Generation of alternatives, 4. Evaluation of alternatives, and 5. Selection of a preferred alternative. Optimization often plays a role in either implementation at lowest cost or maximizing of performance within a given budget. Improvements have been made to the rational planning process, such as exchanging fixed goals for acceptable ranges (Ross 2003), including uncertainty into the evaluation of preferred alternatives (de Neufville 2003), and considering changing goals, values and contexts (Ross 2006) that will impact a system's value delivery in the future. basic nature of the rational planning process- delivering to fulfill a decision maker's goals- however remains unchanged.

Political decision making on the other hand is an emergent process based on consensus and coalition building. Different interest groups fight for the attention of a the decision maker, who has a limited attention span. The decision maker needs to balance multiple competing interests, who may have more or less formal or informal veto power. The ability of a decision maker to propose a project that satisfies a sufficiently large coalition makes or breaks a project. In many cases in the transportation domain, even interest groups without formal decision making power have the power to delay an undesired

project and drive up cost. The option "do nothing" or "do nothing for a long time" is often an alternative to whatever is on the table and can be forced on a project by interest groups if consensus cannot be reached. Unlike in an optimization problem, it is not advantageous and may not be wise to broach controversial value and goal discussions early on in a project, which may increase controversy. In the interest of progressing with a project at all, a savvy politician will need to convince different constituencies of the instrumental value of the project he wishes to pursue to their possibly very different larger goals. The same project can be supported by interest groups with opposed interests who are deriving some intermediate instrumental value from it.

Transportation planning is an example for a complex socio-technical engineering system that encompasses both the technical and political nature of decision making. It is therefore an appropriate example for a case study in which the trade-offs between more technically advantageous and more politically feasible options are illustrated. Transportation planning has its roots in civil engineering. Transportation decision making is therefore traditionally influenced by the rational planning model. It was only later that new considerations, such as equity and environmental concerns, were involved in the decision making process (Dunn 2008). Since transportation systems also function as important public policy levers (e.g., urban regeneration, employment generation) their administration and funding is mainly located in the public domain in many countries including the US, submitting them to political decision making processes.

Both technical and political concerns are important considerations in transportation decision making. Their influence on the actual decision making process is often accidental, resulting in an emergent decision making process that combines aspects from both "schools". A danger in the emerging technical and political decision making process is that technically promising solutions are ruled out early on because they are deemed politically unfeasible, whether this proves to be true or not. On the other hand, what is perceived as politically feasible and uncontroversial may be prohibitively expensive and lead to a deadlock in project planning. In that case, an honest assessment of chances for implementation can openly compare the favored option to a suboptimal alternative with more likely implementation prospects. Given the severe consequences of a wrong assessment of political feasibility and technical performance, both deserve careful attention before any options are ruled out based on concerns either way.

The paper proposes a decision and design method, Multi-Attribute Tradespace Exploration expanded by a policy module, to systematically explore technical and political properties of design options. The method allows for an integrated assessment of both, while keeping technical and political analyses explicitly separate. MATE terminology such as "design options" is clarified in the next section.

The paper argues for a design-exploration process within MATE in two steps. The first one is based on technical performance modeling of a large number of alternatives, regardless of political feasibility. The second one comprises a political feasibility analysis of interesting designs (the policy module).

Technical optimality in the paper is defined performance at cost of the physical system that is designed to meet a value-based, specified goal. Political feasibility is measured by the ease of implementation and public acceptance as perceived by a decision maker.

MATE was developed as a decision making method that supports the exploration of a large number of designs early on in the decision making process. In this paper, the author cites the first application of MATE to a problem in the transportation domain. In the case study it was observed how the solution space was narrowed early on due to political considerations. It is demonstrated how high-level, low-fidelity modeling of alternative solution concepts strongly suggest alternative promising solutions from a cost-performance stand point that should be considered. The case study in this paper further shows that political feasibility is not a constraint but can be modified

The structure of the paper is as follows: Section 2 introduces the method MATE. Section 3 outlines the case application to the Chicago airport express. A detailed discussion of the individual steps of the application of MATE to the case study is provided in (Nickel 2010). Section 4 discusses results from the MATE analysis without a policy module. Section 5 comes back to the political dimension of the case study and section 6 presents additional considerations that impact decision making. Based on MATE and the discussion of political considerations, section 7 offers a recommendation for the City of Chicago in the presented case study. Section 8 demonstrates how a policy module can be integrated into the MATE process to systematically address political concerns that were previously not addressed during the MATE analysis. Section 9 concludes.

2. Emerging method: Multi-Attribute Tradespace Exploration

Multi-Attribute Tradespace Exploration (MATE) is a value-based decision and design method developed at MIT using aerospace cases (Ross 2003; Ross 2006). The Chicago case study presented in the next section in this paper constitutes the first application of MATE to a transportation case (Nickel, Ross et al. 2009; Nickel 2010). Unlike in previous applications within the aerospace domain, constraints in the transportation domain are predominantly political and not technical or due to the laws of physics.

Benefits of MATE include

- Support in the generation (not only evaluation) of design concepts,
- Generation of a large number of alternative design concepts early on in the conceptual design phase,
- Visualization and communication of complex system tradeoffs in both technical (design) and preference (value) metrics, and
- Enabling understanding of the broad effects of changes in design variables (elements of a system that can be changed) on the larger system.

MATE combines two techniques used in technical design and decision making: Multi-Attribute Utility Theory (MAUT, Keeney and Raiffa 1993) and Tradespace Exploration (Ross, Hastings et al. 2002). The use of a *value-based* approach in MATE means that in

order to evaluate designs stakeholders' perceived utility is used as decision metric. The steps in MATE to derive the final tradespace are explained below and illustrated in Figure 1 later on in this section. Ross (2003) provides a detailed description of an example 48 step process that can be followed for conducting a (Static) MATE study, which is described in this section.

Design variables (DV_i) are designer-controlled, tradable quantitative parameters that, as a vector DV= (DV_1, DV_2 ... DV_m) 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 system architecture concepts. *Attributes* are features of a product or system that the user takes into consideration when deciding between any two design options. *Architecture concepts* refer to general ways to achieve the specified purpose of the system, such as different mode choices and corridors for transportation systems. Through the process of systematic variation of design variables to enumerate all possible design vectors the creative solution generation process of designing an engineering system is supported by MATE. The process of combining different resources may lead to novel combinations that the designer may not have considered before.

Modeling

The assessment of level X_i of attribute X^i of any design vector DV requires the *modeling of underlying relationships*, including any cost relationships. These design variable-attribute models and design variable-cost models translate design vectors $DV_{1..m}$ into attribute vectors $X_{1..n}$. The models can be as crude or refined as desired and feasible within the available resources. An understanding of a basic mathematical representation of the causal relationship is a necessary prerequisite for the development of a model in equation form. Additionally, in order to create parametric models, the modeling relationship needs to be understood in a general way and not just from ex-post fitting and extrapolation of models to available data for specific examples. MATE models can be of different forms, for example parametric models, bottom-up models or look-up tables (the last one is not a parametric model).

Utility and expense functions (Multi-Attribute Utility Theory)

MAUT makes possible the calculation of the overall utility of multiple attributes and multiple utility functions, and serves to capture ranges of user requirements in MATE. *Utility or expense functions* translate performance (expressed through attributes) into utility (or expense) by eliciting how much a specific level of an attribute is worth to a decision maker. While utility refers to desirable traits of the system, expense refers to properties that the designer wants to keep at low levels. The idea of expense is akin to the idea of negative utility. All concepts discussed for utility apply equally to expense, however in an inverse way. A utility of 0 and a utility of 1 have meaning to the particular decision maker, for example "minimally" and "fully" satisfied. An expense level of 1, on the other side, denotes complete dissatisfaction and an expense level of 0 denotes minimal dissatisfaction. A stakeholder wants a lot of utility and little expense in a design. An ideal design would therefore have the coordinates (E(X)=0, U(X)=1), indicating maximal utility and minimal expense.

Single-attribute utility is a dimensionless metric representing the satisfaction derived from having a certain level of a single attribute X. *Multi-attribute utility* is the joint utility level derived from having specific levels X_I of multiple attributes X[1]. Generating multi-attribute utility functions which accurately reflect a decision maker's preferences can be difficult. In equations, the single-attribute utility derived from value X_i (level of attribute X_i) is $U_i=U_i(X_i)$. To compare designs that have more than one attribute of interest (n attributes), single-attribute utility functions U_i need to be combined into a multi-attribute utility function U.

Keeney and Raiffa (1976) propose a generalized form of multi-attribute utility functions, the Keeney-Raiffa function:

$KU(X)= \prod_{i=1}^{n} (Kk_iU_i(X)+ 1)$ for $K\neq0$, and

$U(X)= \sum_{i=1}^{n} k_i U_i(X)$ for $K=1$[1]

Single-attribute utility functions can be obtained in several ways. Relatively quick ways are sketching, or derivation by analogy from a known utility function. A more rigorous, but also more time-consuming, way is to elicit single-attribute utility functions in a *structured utility interview* with stakeholders. In order to satisfy the axioms of Multi-Attribute Utility Theory (Keeney and Raiffa 1993), the analyst must ensure that the attribute set is defined by the decision-maker; including precise definitions for each attribute with units, an acceptable range $[X_{iMin}, X_{iMax}]$, and a monotonic preference for the direction of increasing goodness. $U_i(X) =0$ is set at the value $X_{iMin\ of}$ an attribute that is the least desirable, but still acceptable. $U_i(X_i)= 1$ is set at the most desirable value X_{iMax} of an attribute.

Tradespace Exploration

Tradespace exploration is a method for understanding complex solutions to complex problems. It is a model-based tool that makes possible a low-fidelity up front assessment of the properties of many designs. A *tradespace* is a graphical representation and database of supporting data and mathematical models of all possible solutions to a design problem. The possible solutions are created by systematically enumerating the design vectors, which are made up of design variables. Each *design vector* characterizes an individual design. The trade-offs between different designs refer to either different levels of resources that are committed, or to different characteristics of performance that are acquired as a consequence of the amount of resources that is spent on them. The *exploration* part in tradespace exploration denotes not simply optimization, since it can involve human interaction and creative input to the designer in how the tradespace may

[1] K is a normalization constant and the solution to $K+1= [Kk_i +1]$, and the single attribute utility functions $U_i(X_i)$ and k_i "weights" are elicited from the decision maker whose preferences are being captured in the multi-attribute utility function U(X).

be broadened as a result of its actual shape, as well as the opportunity to learn about the potentially complex relationships between design variables across the tradespace.

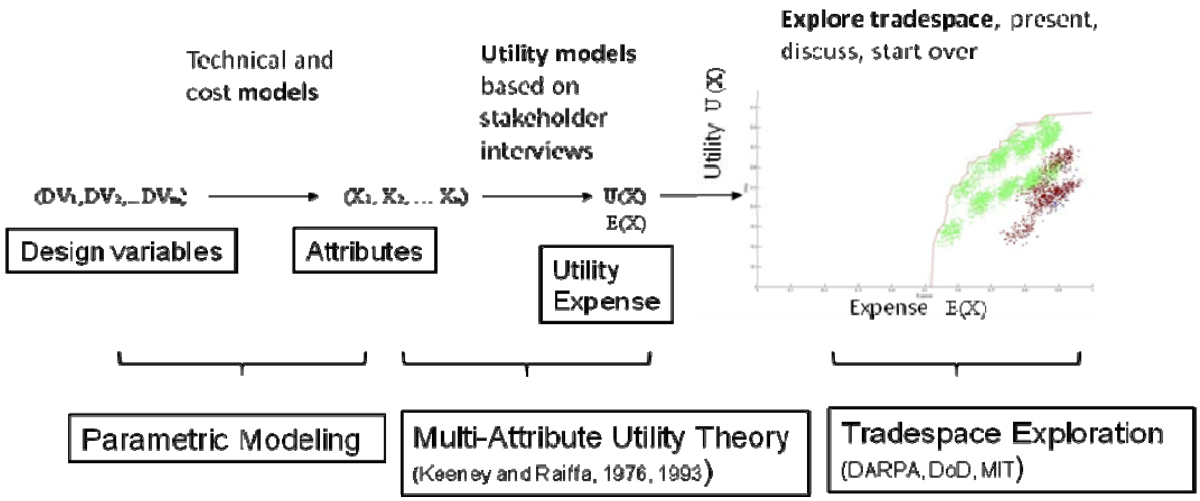

Figure 1: **Steps of the MATE process (single iteration)**

Tradespace exploration is used at such organizations as NASA, DARPA and MIT to analyze large complex engineering projects in the aerospace domain that involve complex resource and performance dimensions and multiple goals held by multiple stakeholders (Ross, Hastings et al. 2002).

Iterations

MATE offers tools for establishing decision criteria and for generating and evaluating solutions. Figure 1 illustrates a single iteration of MATE. The method however calls for a feedback loop between designers and decision makers, since iterating attributes and properties of available technical designs improves the awareness and communication of decision maker values to designers and among decision makers. Naturally, the value as expressed by decision makers is influenced by their past experiences and may to some extent not even be consciously known by them. Through confrontation with the tradespaces as a result of low-fidelity technical modeling, decision makers understand the relationship between their expressed attributes and properties of available designs and may, through the increased insight, be led to change their values in a subsequent iteration. The *MATE process* denotes the sequence of steps of performing MATE studies and discussing the results to refine inputs for the MATE study in the next iterative step.

3. Case study: Chicago Airport Express

This section provides a high-level description of the case study, omitting a number of assumptions. An extensive description of the MATE process and its application to this case study can be found in (Nickel 2010) in Chapter 4.

The goal of this case study is to explore different options to improve access to O'Hare International from downtown Chicago (the "Loop"). An underlying understanding exists among the decision makers that the clientele for improved access are business travelers and that the express needs to provide a premium service. Proxy representatives for three decision makers were interviewed about their expectations from the Airport Express. The three decision makers are the City of Chicago, the Chicago Transit Authority (CTA), and a Private Operator. The technical and cost modeling was based on technical studies as far as possible and proxy assumptions were data was not available.

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 Chicago Transit Authority (CTA) (Nickel 2010). Both public transit and individual travel (car, taxi) are unsatisfying for airport travelers due to long travel time and inconvenience of transit, or frequent and highly variable congestion on the Kennedy Expressway, respectively. Several technical studies have been carried out since 1998 with the goal of identifying a feasible design solution. The proposals to date focus exclusively *on technically feasible*, rather expensive rail connections.

Attribute elicitation

Since the time for the interviews did not allow for a structured utility interview, only the minimally (x_{iMin}) and maximally (x_{iMax}) acceptable levels of an attribute were elicited. A power-function $U(x)= x^{-y}$ is with y=1/2 is assumed to underlie the utility function (diminishing returns).

Table 1: Expense and Utility for the three decision makers. QOS is an abbreviation for Quality of Service

Attributes	**DM**	**Metric**			**Weight**	**Abbreviation**
Expense			**Min acc e=1**	**Max acc e=0**		
City's initial cost	City	$M	640	100	0.16	CIC
City's cost share	City	%	50%	10%	0.12	CCS
CTA initial cost	CTA	$M	100	0	0.2	CTAC
Operating costs	PO	$/day	10,000	0	0.1	OC
Concession payment	PO	$M	500	0	0.2	CP
Utility			**u=0**	**u=1**		
QOS	City	Scale [1 to 5]	2	5	0.28	QOS
Span of service	CTA	Hrs/day	24	18	0.1	MT

QOS_PO	PO	Scale [1 to 5]	0	5	0.2	QOS_PO
Freedom to make changes	PO	Scale [1 to 5]	1	5	0.15	FC
Competition Agreements	PO	Scale [1 to 5]	3	5	0.15	AB

Design variables

The following design variables were identified for a possible Airport Express. Route 2 is an exclusive train right-of-way, BRT is a dedicated lane on the Kennedy Expressway for Bus Rapid Transit, and BLS (Blue Line Switch) changes the current Blue Line service to bus service and runs a train airport express on the freed-up rails of the former Blue Line.

Table 2: Design variables

DVs	Range	Measure	Abbreviation	Number
Concept	[1, 2, 3]	Route 2, BRT, BLS	Concept	1
Fare level	[10, 20]	$	Fare	2
Frequency	[5, 20]	headway in min	Freq	3
Travel time	[20, 30]	min	Time	4
Amenities	[1,2,3,4,5]	Qualitative Scale, 5 most amenities	Amenities	5
Span of service	[16, ...,24]	hr/day	Span	6
City cost share	[10, 50]	%	CityCostShare	7
Freedom to make changes	[1,2,3,4,5]	Qualitative Scale, 5 most freedom	Freedom	8
Competition agreements	[1,2,3,4,5]	Qualitative Scale, 5 most protection from competition	Competition	9
CTA initial cost	[0, 100]	$M	CTA	10

Modeling

A number of design variables map directly to attributes, such as Competition Agreements and Freedom to make changes (to airport express operations) for the Private Operator. Both Quality of Service attributes (QOS and QOS_PO) are calculated from the service design variables DV_2 to DV_6. Quality of Service is modeled independently of concept, meaning that Quality of Service on a bus can be as high as on a train. The other models are parametric cost models (Operating Cost and City Cost, based on construction cost and the design variable City Cost Share). The Private Operator Concession Payment is modeled as willingness to pay, depending on concept and service variables.

4. Discussion of tradespaces

Based on the utility and technical models discussed in the previous section, tradespaces are plotted. Multi- Attribute Utility is plotted on the y-axis, Multi-Attribute Expense on the x-axis. The attributes that feed into those functions are listed next to the axes. Utility and Expense functions are weighted sum functions using weights for individual attributes that were elicited in the stakeholder interviews. The tradespaces were plotted in MATLAB® for a design space size of n=20,000, using a random sampling algorithm. The actual yield of financially feasible designs however is lower. The total size of the design space is 3.6B. The red line indicates the Pareto Front, consisting of the designs that provide the highest utility for a given expense level. All tradespaces are colored by concept choice (DV_1). The CTA tradespace does not provide interesting insights and is therefore not discussed in this paper. Figure 2 and 3 show the tradespaces for the City of Chicago and the Private Operator.

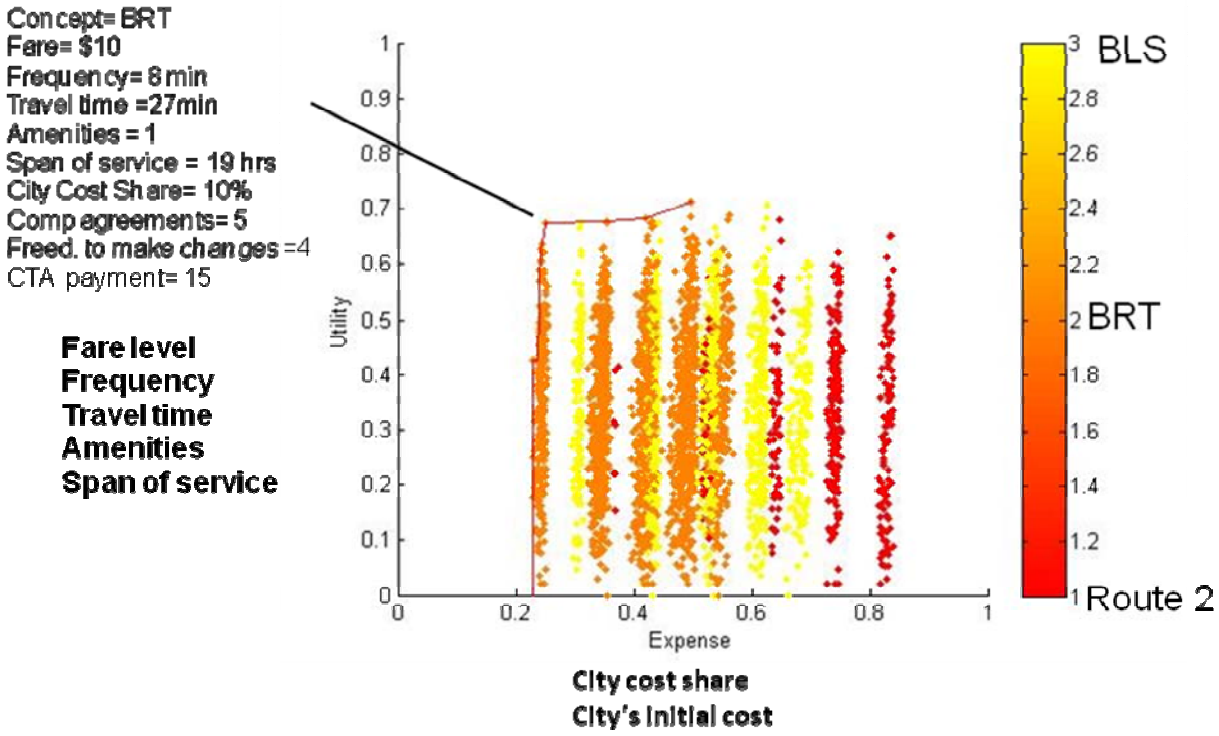

Figure 2: City of Chicago Tradespace, colored by design concept, n=20,000

The promising design in the upper left corner in the City tradespace is specified in Figure 2.

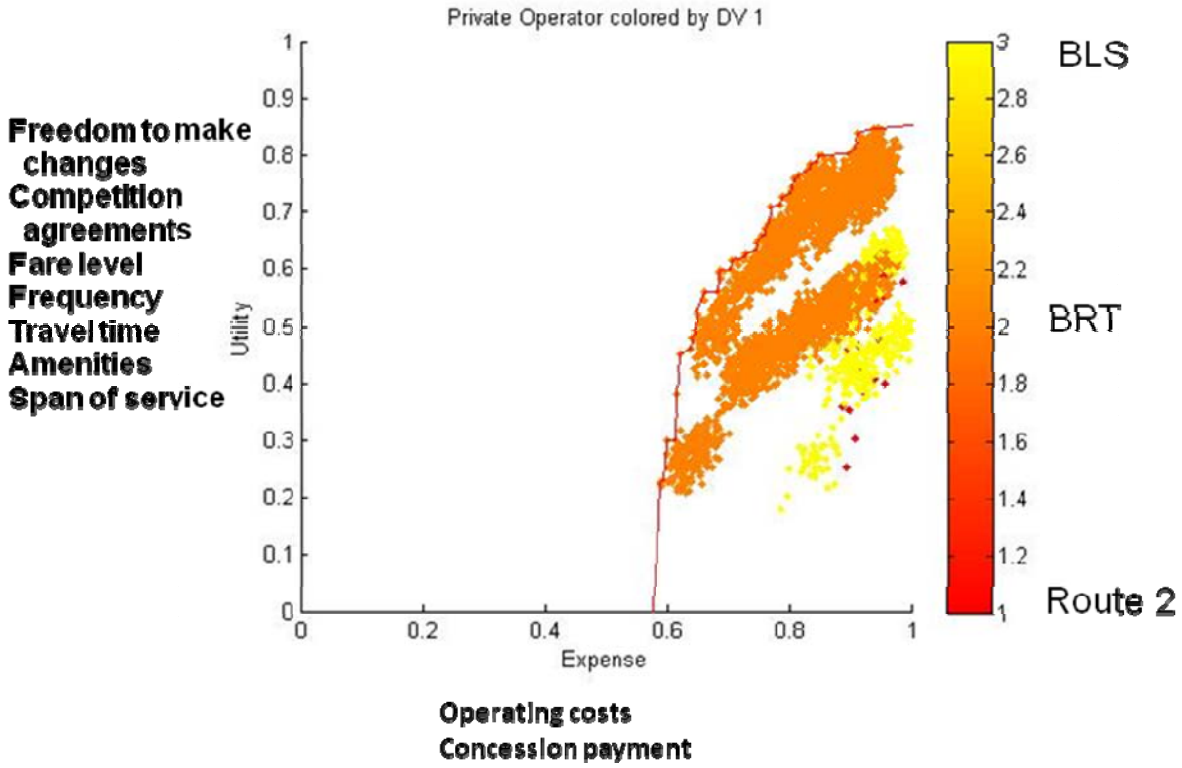

Figure 3: Private Operator Tradespace, n=20,000

The Private Operator tradespace includes very few red designs because of constraints on acceptable Operating Cost. A higher allowance for Operating Costs leads to more feasible red (Route 2) designs. The City only contributes to initial cost and therefore has no constraints on Operating Costs, leading to more feasible red designs.

The following observations can be drawn from the tradespaces.

1. A clear pattern of grouping of designs of the same concept is visible. Choice of concept dominates a design's utility and expense.

2. BRT is the pareto-optimal concept for both decision makers.

3. Route 2 (red), the only concept that has been considered in actual technical studies, comes at a much higher expense for the same level of utility than BRT.

Based on the MATE analysis, which is largely based on technical design factors, BRT emerges as the optimal concept from a performance at cost point of view for both decision makers. BRT had been ruled out early on in the design process because of prestige concerns that a bus might fail to attract the targeted premium traveler segment. First studies on options for an airport express go back until the early 1990s, looking at different train corridors. The high price tag of feasible options is the reason that the airport express has not been implemented to date. A conversation with a different planner at the CTA confirmed that BRT is a feasible option and should be considered.

The tradespaces show that a disconnect exists between the design concept preferred by decision makers (a separate train right-of-way) and the technically Pareto-optimal design concept (BRT), based on the MATE analysis. A tradeoff exists between technical and political feasibility of design concepts in this case study. The tradespaces also show that cost is incurred by ruling out designs early on in conceptual design. Cheap designs are eliminated, leaving only those that are prohibitively expensive.

5. The political feasibility dimension

Political feasibility is crucial in the evaluation of public transportation systems. Public transportation systems are complex socio-technical systems, deeply integrated with their surrounding environment. New transportation construction affects people directly in their mobility and – for better or for worse- quality of life, giving rise to several interest groups that are personally affected by the proposed system. Transportation systems are vital for the functioning of society and typically come at large capital expense, preventing them from operating financially self-sufficiently and making them dependent upon public funding. Often being a natural monopoly, many transportation systems are subject to regulation and administration by government-owned authorities. For these reasons, broad public interest exists in the selection, financing and implementation of new transportation projects. Since public transportation system impose both costs (e.g., financial, environmental,) and provide benefits to society (e.g., reduced travel time, agglomeration, cohesion, accessibility), political decisions regarding the distribution of welfare are inseparable from most public transportation projects. Expertise of both policy makers and traffic/construction engineers is hence needed for successful planning, selection and implementation of transportation projects.

A crucial consideration for political feasibility is public acceptance and potential unintended adverse effects that can be caused in an interconnected complex technical infrastructure system. Literature describes the often fuzzy nature of political problems, the lack of a good cause-effect knowledge base and the danger of producing new problems when attempting to solve existing ones. Without a clear knowledge of a cause-effect relationship for "fuzzy" factors, such as public acceptance, they cannot be treated in the same way as much better defined performance attributes in MATE.

In applying MATE to a design problem in the public transportation domain, the effects of having to make technical decisions under extensive public interest and scrutiny on the nature of the decision making process become visible. The question of whether something is politically realizable at all is crucial, since the alternative is always to do nothing. A possible reaction even by non-decision makers to non-favored designs is always to try to prolong the process of decision making, resulting in increased cost and weakening the prospects of an eventual implementation. The question of whether stakeholder alignment on any one solution can be achieved at all is therefore as important, or even more important, than which actual technical design is chosen.

If MATE is to be applied to public transportation design, the fuzzy concerns of political feasibility need to be able to be addressed. The following section discusses political concerns for the case study on the Chicago Airport Express. Those concerns were not

brought up in stakeholder interviews, and without an explicit section examining political feasibility, they would have been overlooked.

6. Discussion of political feasibility

In this section, additional considerations for political feasibility are addressed qualitatively.

Bus Rapid Transit

Even the most promising concept, BRT, presents implementation challenges.

1. *Underused resources*. Even at a very short headway of 3-5 minutes, car drivers on neighboring lanes would see an underused lane with no occupation during several minutes while stuck in traffic. This situation will produce resentment.

   Mitigation: The problem can be mitigated by opening up the dedicated BRT lane to other cars against payment of a toll. That way, cars willing to pay for a less congested street can do so and reach their destination faster. The eventual details of merging different lanes and collecting tolls need to be worked out by traffic engineers. The success of this mitigation strategy depends on technical execution. The competitive advantage of the buses would be lost to some extent, but the toll and an additional airport fee for taxis may help prevent cannibalization of the airport bus through limiting the number of cars on the tolled road.

2. *Danger of increased congestion on other lanes of the Kennedy Expressway by dedicating one lane to BRT.* A discussion about capacity reduction on the Kennedy Expressway in section 4.6 of (Nickel 2010) shows that BRT service will likely offset the capacity reduction if one lane in each direction were to be dedicated to BRT, assuming that 3,600 passengers daily are diverted to the Airport Express and have formerly traveled on the Kennedy Expressway at an average car occupation of 1.2 travelers. This number corresponds to 72% of the 5,000 airport travelers that the CTA assumes will be using the newly constructed Airport Express per day. The remaining 18% may be diverted from former Blue Line use or induced. While these estimates are subject to various uncertainties, a reasonable possibility exists that congestion would not worsen on the Kennedy Expressway and average car travel speeds would not be impacted. If car travel speeds were to be impacted negatively, political will would be necessary to implement BRT while making car travelers on the Kennedy Expressway worse off.

   Mitigation: Promoting diversion of airport-bound travelers to use the Airport Express, opening up BRT lane to High Occupancy Vehicles (possible against payment of a toll) to reduce number of cars

The Blue Line Switch Option

The Blue Line Switch (BLS) option consists of a BRT service with frequent stops along the Kennedy Expressway which would replace the current local service between the Loop in Chicago and O'Hare. The freed-up Blue Line tracks would then be used for an

exclusive, non-stop Airport Express. The BLS option in its core is the change from a major train operation (Blue Line) to a major bus operation (BRT along the Kennedy Expressway).

Direct employment generation from the BLS option is complicated to evaluate. Shutting down the Blue Line reduces jobs, whereas the new rapid bus system creates jobs. Those jobs cannot be easily substituted for each other: more drivers are needed for the bus operations, but more mechanics are typically needed for Heavy Rail and track maintenance than for BRT. Despite a possible net increase in jobs, workforce turnover may incite resistance from unions and create bad press for the CTA. Keeping on as many employees as possible, the CTA would still incur training costs for those employees who need to be retrained from train operator to bus operator, and from train mechanic to bus mechanic (assuming this is possible and employees agree to the change).

Another implementation concern is the siting of stops along the Kennedy Expressway, as well as passenger safety and accessibility of those stops.

Route 2

Route 2 is a separate train right-of-way for an Airport Express, not interfering with the current Kennedy Expressway or the Blue Line. It is politically the least controversial option. The major complication is its high price tag which prohibited implementation in the past.

Concerns independent of architecture concepts

1. Dispersion of investment

Operating costs for electricity would remain in the City of Chicago, whereas both expenses for vehicles and fuel for BRT and the Blue Line switch option would leave the state of Illinois. This argument may be advanced by opponents to the BLS Option, which requires the largest investment in new vehicles and fuel. Those considerations are especially acute in times of an economic downturn and carry more weight depending on the agenda for regional economic stimuli that the project has presently and in the future.

2. Uncertainty and Scalability of operations

Uncertainties related to this project include ridership development, enplanement growth at O'Hare, mix of Airport Express riders (former transit users, former car users, induced new travelers), and diesel and electricity prices. The airline industry is traditionally a highly cyclical industry, which is expected to directly affect Airport Express ridership. An airport express concept with lower capital costs and higher operating costs allows a better response to a changing demand pattern. BRT and the Blue Line switch option are advantageous from this point of view, since scaling back of operations in times when demand is slow has the greatest impact on cost savings when variable costs are high. Through the lower capital costs for BRT than for Route 2 (no maintenance of right of way, less capital for rolling stock), capacity can more easily be added if demand exceeds projections.

7. Recommendation for the City of Chicago

BRT emerges as the Pareto-optimal architecture concept from tradespace exploration. Political impediments exist, but can be managed. Public acceptance can be increased by stressing the benefits of BRT: low cost compared to a separate train right-of-way and scalability. Capital expenditure for BRT is low enough for the CTA and the City of Chicago to self-finance this option, making them independent from the concession payment of a Private Operator. Without the need for a financial contribution, it will be easier to find a private party able to manage operations at a profit.

The major caveats of BRT are the political will required to dedicate one lane of the Kennedy Expressway to BRT and prestige concerns. To secure political will for a dedicated lane, it could be opened up to other cars against payment of a toll or to high-occupancy vehicles. This initiative can be explained to the public as providing the option of faster travel for a fee, while not forcing anyone to pay for what was free previously.

Prestige concerns with airport travelers can be addressed by marketing campaigns at O'Hare, clearly conveying that BRT is the fastest and most reliable travel option to downtown. Amenities like air-conditioning, space and power outlets for laptops change the look-and-feel of a bus and achieve the same level of comfort found in airport trains. Even if BRT might not be preferred by airport travelers if a train were available, it may very well be possible to convince them that it is their best available option. To put the discussion about the potential negative image of BRT on a more objective basis, interviews at O'Hare should shed light on the true preferences of the targeted customers.

The discussion of political feasibility considerations in the previous sections not only exemplifies political feasibility concerns that have not been brought up in the earlier stakeholder interviews exploring desired performance. Fuzzy political concerns, such as public acceptance and implementability, are important and valid considerations when making a technical design selection. Mitigation strategies for some of the issues in this section show that political feasibility can sometimes be changed. It follows that not only should designs not be ruled out because of political concerns at an early point in the conceptual design phase, but rather that options to increase political feasibility should be explored systematically. The following section discusses how a policy module can be introduced into the MATE process and can support the derivation of new design variables that can modify political feasibility.

The final section presents a MATE process that has been expanded and contains a policy module.

8. Integrating a step into MATE to assess political feasibility

Public transportation planning requires experts with technical and public policy expertise to work together. Those individuals do not always speak the same language and may come from very different training backgrounds. The MATE process expanded by a policy module can serve as a communication tool between people from different backgrounds in urban planning, transportation engineering and public policy.

Table 3 recaptures the main political implementation concerns raised earlier and which additional design variables, if any, may increase implementability. As discussed, prestige

problems arising from BRT can be mitigated by the two levers marketing and lane use policy.

Table 3: Implementation concerns and possible mitigation

Concept	Implementation concern	New design variable
Route 2	Financing	-
BRT	• Image/ Prestige • Visibility of underused dedicated lane • Increased congestion on Kennedy Expressway	• Marketing of service • Lane use policy
Blue Line Switch Option	Workforce turnover	-

The case study so far has demonstrated that a) designs should not be ruled out early on because of political feasibility concerns, since those concerns can sometimes be mitigated (Table 3), and b) a simultaneous focus on political feasibility and technical optimality brings up those new design variables that can mitigate implementation concerns, thereby broadening the design space, and helping to make more informed (better) decisions.

This last section of the paper suggests how MATE can be used as a process that systematically addresses both technical feasibility and political optimality. Tradespaces lend themselves to refinement in several iterations, which can be discussed and refined again with people from different backgrounds, providing a common basis for discussion.

Figure 4 shows the new step during which the tradespace is presented to experts in the policy environment and practical implementation concerns. These experts may be decision makers as well, but they don't have to be. They can be planning staff that is asked for their opinion regarding several options on the table. It is important to focus on technical performance in the utility interviews and modeling and address concerns for coalition building and likely support in the policy step, if individuals act in dual capacity as decision makers and "implementation experts".

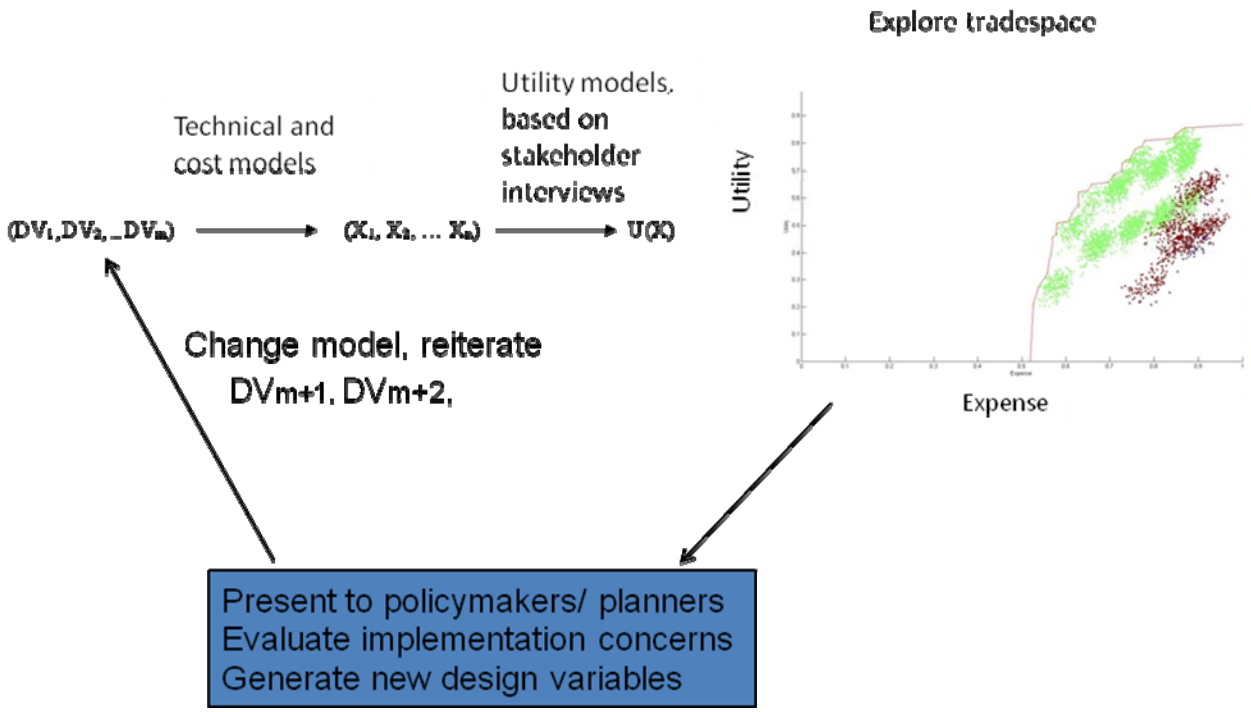

Figure 4: MATE process including policy module

For the sake of separating political and technical analysis, decision makers are asked to disregard political feasibility and coalition building when expressing their performance attributes in the earlier utility interviews. The tradespace generated in iteration 1 (T_1) is first discussed with the decision makers, and subsequently presented to policy makers/planners who are familiar with implementation concerns. In the case study, they would likely express additional concerns such as those discussed in the previous section, which were not brought up in the utility interviews. Those concerns are systematically logged for different concepts or design groups (e.g. those that share certain design variables that pose an implementation problem). Subsequently, policy makers and planners are asked if they can think of ways to mitigate implementation concerns. In the case study, additional design variables could be Marketing expense on BRT (DV_{m+1}) and Options for lane use (DV_{m+1}). Marketing expense would drive up the attribute operating cost and impact certain decision makers' utility of BRT. Options for lane use can for example be (1) Opening up for cars against payment of a toll, (2) Opening up for High-Occupation Vehicles (HOVs), e.g. those with more than three occupants, (3) Opening up to HOVs and non-HOV vehicles against payment of a toll, (4) open up for cabs, (5) do not open up BRT lane for any cars. Another promising mitigation measure (not relevant however in this case) is the buying off of opposition, which also increases the project budget.

These additional design variables are handed over again to technical analysts together with any feedback from presenting tradespace T_1 to the decision makers, who commented on congruency of the tradespace with their utility from different designs. In a second iteration utility curves and multi-attribute utility functions may be changed and the model expanded to include the new design variables. In the case study, a traffic engineer will be

needed to assess if and how toll booths can be accommodated along the BRT lane, how much the payment or control process would slow down traffic flow, how much revenue can be expected, and what effect different lane use policies would likely have on competition and travel behavior. The new tradespace (T_2) is presented again first to decision makers, second to implementation experts. Decision makers again express their comfort with the tradespace and to what extent it expresses their true preferences. Policy makers assess the new design options with regard to their political feasibility and desirability. At this higher level of granularity, new implementation concerns come up: a joint lane for BRT and cabs might be highly efficient for airport travelers, but the cabs would likely cannibalize bus service or at least reduce its attractiveness. Toll payment may slow traffic flow down to much, increasing likely opposition from car travelers on the Kennedy Expressway. If toll payment appears attractive overall to decision makers after viewing the second iteration of the tradespace, a traffic engineer can refine the analysis in a third iteration by modeling different payment options (electronic pass, cash, monthly flat rate with electronic pass or vignette in window, etc). T_3 is feedbacked again. The involved parties learn about the interrelationships between political and technical considerations, as well as how a large number of different designs perform at a high level. Eventually, a decision must be reached through negotiation where no single decision maker exists.

A special benefit of the tradespace in this process is that if at any point a design is ruled out because of political concerns, the decision maker who so chooses sees exactly the "goodness" of the design he rules out and how it compares to remaining designs. In other words, if a Pareto-optimal design is eliminated and the new design that promises the next highest performance at the given cost level and higher political feasibility (albeit less performance than the eliminated design), the decision maker knows exactly how much performance he is trading in for increased political feasibility. The decision about resources that are spent on further exploration of remaining designs is placed on a more informed basis.

It can be expected that the presented method, MATE extended by a policy module, will contribute substantially to the avoidance of sub-optimization where Pareto improvements are possible, or alternatively to contribute to a more informed decision to sub-optimize when required by political reality.

9. Conclusion

A challenge in transportation planning is the explicit consideration of both political expectations and technical properties of different design concepts. The case study in this paper demonstrates a disconnect between the politically most feasible design concept (a separate train right-of-way), and the technically Pareto-optimal design concept (Bus Rapid Transit) for a proposed airport express for the City of Chicago.

The case study further shows that limiting the solution space early on is costly. The cost of ruling out certain designs based on perceived political unfeasibility is demonstrated visually in tradespaces. It is demonstrated in the case study how the political feasibility of certain design options can be modified. It follows that a) designs should not be ruled out early on because of political feasibility concerns since those concerns can be mitigated,

and b) simultaneous focus on political feasibility and technical optimality broadens design space, and can help make more informed and hence better decisions.

The MATE process expanded by a policy module is presented as a new method to consider both technical performance and the fuzzy nature of political implementation concerns in decision making. The fact that public perception can be influenced by marketing campaigns and endorsement by politicians shows that political feasibility can indeed be an attribute that can be changed, and does not need to be a hard constraint. Factors exist, e.g., use policies, marketing, system design, bribes, that change political feasibility and acceptability. By embedding a module into MATE to make political concerns explicit, those concerns can be discussed together with their possible modification. If modification is possible, new design variables are derived and the tradespace is enlarged. Design variables such as "marketing" and "endorsement" may however not be fully understood and not be able to be modeled in a quantitative way. It is therefore suggested to treat them differently from technical design variables, whose impact system performance is more clearly understood and can be modeled. The policy module offers a way to openly address "political messiness".

Tradespaces are suggested as communication tool for conversations between people from different disciplines involved in transportation planners, such as transportation and civil engineers, economists, planners and policy makers. Tradespaces lend themselves to refinement in several iterations which can be discussed again with people from different backgrounds, successively incorporating their different expertise in a joint visual that presents information in a common language to all involved.

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Any views expressed in this paper are those of the author alone and do not represent official positions by the CTA or the City of Chicago. The modeling effort is based on technical studies and personal interviews, but departs from an accurate representation of the situation in Chicago due to proxy assumptions where data was not available. The purpose of this paper is to demonstrate and discuss concepts and not to provide technical guidance.