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A new evaluation and decision making framework investigating the elimination-by-aspects model in the context of transportation projects' investment choices

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ABSTRACT

The Transportation Elimination-by-Aspects (TEBA) framework, a new evaluation and decision making framework (and methodology) for large transportation projects, is proposed to elicit, structure and quantify the preferences of stakeholder groups across project alternatives. The decision rule used for group decision making within TEBA is the individual non-compensatory model of choice elimination by aspects (EBA). TEBA is designed to bring out the decision rule employed by decision makers when ranking the options presented, incorporate various criteria types and ease communication of relevant information related to options and criteria for multiple stakeholder groups. It is a platform for democratizing the decision making process. The TEBA framework was tested using a case study investigating alternative land connections between Beirut and Damascus. Key results showed that (1) stakeholders have employed EBA in making decisions, (2) a defined group of decision makers will rank options differently when provided with modified sets of criteria, (3) the public sector and general public groups ranked Impact on Employment among the top criteria, (4) the most important criterion per group from EBA was as expected; (5) the EBA analysis suggested that only 3–4 criteria are significant in reaching a decision; (6) aggregation of user assigned weights masked relative importance of criteria in some cases; and (7) analysis of user assigned weights and Minimum Threshold (MT) values suggest higher risk perception with increased criterion importance. Policy implications include recommendation to reach out to stakeholders for input on decisions, including the “people” but refrain from relying on criteria weights assigned by “experts” and reduce the “experts”' role in decision making. Also, it is recommended to model the decision making in a probabilistic framework rather than a deterministic “one score” approach, seek to identify a consensus ranking, place particular attention on determining the values of the criteria that emerged as “top” at the evaluation stage and continue to emphasize risk measures.

1. Introduction

In recent years, non-physical communication networks have achieved revolutionary progress. Despite that, physical transport of people and goods remains a national and international need, as evidenced by facts such as annual investment in transport infrastructure in the CEE countries typically around 1–2% of GDP (Short and Kopp, 2005) and the UK announcement in 2010 of a 200 billion pounds in investments in infrastructure over the next 5 years (Sassoon, 2010). Transportation investment projects are strategic endeavors with high impacts both at the macro-economic level and at the financial level given their capital intensive nature. Several alternative options are typically identified for any given project (Bristow and Nellthorp, 2000). The options[1] are evaluated by determining a set of criteria for evaluation and assessing the performance of each option with respect to those

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[1] For example, in order to connect 2 points A and B, the options include: different highway routes, different rail routes and technologies, air transport, sea transport. As another example, consider prioritizing independent developments competing for funds; the options in this case could include: a highway project, an urban roads network upgrade, a metro system.

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criteria (Adler, 1987). Evaluation of options is a complex task and the reader is referred to Adler (1987), de Palma et al. (2007) and de Palma et al. (2013) for details. A preferred option (or a ranking of available options) is determined based on the results of the evaluation, e.g. Cost Benefit Analysis (CBA) (Small, 1998). The decision making model that governs this latter step in the process has been insufficiently researched (Sayers, Jessop and Hills 2003, Priemus and Bert, 2007). Moreover, fit-for-purpose criteria and risk measures, accounting for multiple stakeholder views, as well as ability for synthesizing a decision from multiple groups' decisions remain challenges within the current process despite work by de Palma et al. (2009), Berechman (2009), Salling and Banister (2009), etc. The purpose of this paper is to address some of these issues: We propose an evaluation and decision making framework to elicit, structure and quantify the preferences of stakeholder groups across project alternatives.

The most common decision making methods are CBA, when only monetizable criteria are considered, and/or some form of Multi-Criteria Decision Analysis (MCDA) procedure. The MCDA methods reported to have the most success include Linear Additive Models (Keeney and Raiffa, 1976), Analytical Hierarchical Process (AHP) (Saaty, 1980) and multi-attribute utility theory (MAUT) (Sayers et al., 2003, Quinet, 2000). The generally applied paradigm in the literature and in practice is clearly one of relative weighing and arithmetic aggregation (Tsamboulas, 2007; Sayers et al., 2003). Some of the key issues that were highlighted with such approaches include inconsistency and lack of transparency in understanding the underlying logic leading to a decision i.e. the decision rule and preferences amongst the criteria used in reaching the decision as well as the rank reversal phenomenon (DTLR; Wang and Luo, 2009). Additional challenges to a wider application of the more popular linear additive and analytical hierarchy models in the context of transportation investment project selection include the need for alternatives to be settled in weak preference relation, the need for any two parameters to be in a constant relative compensation and the need for basic parameters to be monotonous (Cundric et al., 2008).

The DEX model (Cundric et al., 2008) and the work by Nellthorp and Mackie (Nellthorp and Mackie, 2000) are noted attempts to overcome these challenges. However, the DEX falls short in responding to several critics such as its low sensitivity to small differences between alternatives and weakened transparency and increased effort in dealing with larger numbers of options and Nelthorp and Mackie's model does not deal with the aggregation of preferences.

Based on our review of the latest attempts at improving decision making frameworks, our understanding of the key characteristics required in a decision model for transportation investments decision making, and our understanding of the Elimination By Aspects (EBA) model characteristics and methods described in more detail in Section 2, this paper presents the Transportation Elimination-by-Aspects (TEBA) framework, a new evaluation and decision making framework (and methodology) for large transportation projects. TEBA is not an attempt to replace CBA, but rather takes CBA a step forward. While CBA does not indicate how multi-dimensional preferences may be aggregated, this research proposes one way to do so with TEBA. TEBA is proposed to elicit, structure and quantify the preferences of stakeholder groups across project alternatives. The decision rule used for group decision making within TEBA is the individual non-compensatory model of choice EBA. TEBA is designed to bring out the decision rule employed by decision makers when ranking the options presented, incorporate various criteria types and ease communication of relevant information related to options and criteria for multiple stakeholder groups. It is a platform for democratizing the decision making process. The TEBA framework is tested using a case study investigating alternative land connections between Beirut and Damascus. The case study is used to analyze and compare, across three key stakeholder groups including the Public Sector, the Private Sector and the General Public groups (i) options rankings, (ii) criteria preferences, and (iii) a consensus ranking of options.

The next section elaborates on the EBA model. Section 3 describes the TEBA framework. Section 4 presents a case study application of the TEBA framework and walks the reader through details of TEBA implementation as well as results from that case study. Section 5 concludes with key insights, contributions and policy implications.

2. The elimination-by-aspects model

The elimination by aspects model discussed here offers a non-compensatory probabilistic alternative to existing decision models of choice. Non-compensatory models are very important, and have received very little attention in Transportation. Our approach:

1. uses the concept of minimally acceptable levels of attributes proposed by Simon (1955) and Young (1984),
2. uses a lexicographic approach to decision making while relaxing the requirements of *a priori* ordering of alternatives,
3. generalizes the choice model of Luce (1959) whenever the alternatives are composed of disjoint aspects, and
4. generalizes the choice model of Restle (1961), who developed the representation of choice alternatives as collections of measurable aspects, whenever only binary choice probabilities are considered (see Tversky, 1972a, 1972b; Ranyard, 1976).

Tversky introduced EBA as "a probabilistic theory of choice, based on a covert elimination process, which accounts for observed dependencies among alternatives". It is a non-compensatory model that adopts an elimination approach to alternatives that do not meet satisfaction level of a selected aspect, starting with the most important aspects and proceeding recursively (Tversky, 1972a, 1972b).

EBA belongs to the family of discrete choice models in that it defines a probability for the choice among available alternatives. Its decision rule is a combination of lexicographic and satisfaction rules (see the early presentations in Ben-Akiva and Lerman, 1985 and Anderson et al., 1992). EBA has typically been employed as a descriptive model of choice mostly popular in marketing and psychology (Fader and McAlister, 1990; Wickelmaier and Schmid, 2004; Laurent, 2006) but has also been used in other contexts such as transportation demand analysis and residential choice (Kato and Kosuda, 2008; Young, 1984). Applications of EBA as a prescriptive model exist as well (Gati and Fassa, 1995).

For every experiment, the process starts with a clear identification of alternatives and criteria. An alternative is a viable option that the decision maker can choose; e.g. a toll highway vs a high speed railway connection between points A and B. A criterion is a measure by which an alternative may be judged; e.g. Net Present Value (NPV) or travel time. The next step is to evaluate/analyze each alternative and report the value of each criterion for each alternative in a performance matrix. For criteria that are quantifiable, a Minimum Threshold (MT) is set based on expert knowledge and is fixed thereafter or alternatively left for each individual to set prior to decision taking. The performance matrix is used as a basis to build the "utilities matrix": When a criterion meets the MT for an option, a utility scale is assigned for that criterion for that alternative; a zero is assigned otherwise. The utility scale represents the importance of a criterion or, more specifically, it determines the probability that the criterion is chosen to guide the

Table 2.1
EBA example: performance matrix.

Project	Criterion				
	C1	C2	C3	C4	C5
Option 1	100	5	12	7	10
Option 2	200	2	23	5	90
Option 3	300	1	4	7	100

Table 2.2
EBA example: utility matrix.

Project	Criterion				
	C1	C2	C3	C4	C5
Minimum threshold	***> 50***	***> 4***	***> 10***	***> 6***	***> 50***
Option 1	u_1	u_2	u_3	u_4	0
Option 2	u_1	0	u_3	0	u_5
Option 3	u_1	0	0	u_4	u_5

elimination process.

We illustrate with a simple example. The illustrative reduced performance matrix shown in Table 2.1 includes hypothetical options, criteria, and analysis results for each criterion for each option.

The EBA model formulation requires the set-up of utility matrices, which requires the assignment of a minimum thresholds (MT) vector. This is illustrated in the utility matrix in Table 2.2 for the performance table in Table 2.2.

Generally, for every individual decision maker, the decision process proceeds as follows:

Step 1: identify and remove all criteria that meet (or donot meet) the thresholds for all alternatives

Step 2: select the aspect that is most important in making a decision,

Step 3: remove the alternatives that do not possess or meet the MT requirements of the selected aspect,

Step 4: repeat steps 2 and 3 until either no more criteria remain to guide further alternatives elimination or only one alternative remains (Tversky, 1972a, 1972b; Anderson et al., 1992).

Investigating EBA as the decision rule underlying the choice processes in the TEBA framework represents a shift from the numerical weighing paradigm and models the transportation investment choice problem as a probabilistic event. EBA is selected for investigation in the TEBA framework because it is a probabilistic, non-compensatory, model of choice that generates a probability of choosing a preferred option or the probability of a preferred ranking of options at the aggregate level and overcomes compensation issues that arise from MCDA models, it has the flexibility of integrating performance measures of different natures (quantitative and qualitative) and allows for these measures to be reported in their natural units, which makes them more informative and intuitive to the user, it allows the estimation of the relative "utility scales" of the criteria, which reflect the relative importance of the criteria, for multiple groups of decision makers, and is a heuristic characterized by a favorable effort to quality ratio.

For a mathematical formulation of EBA[2], we start with some definitions. Define A as the set of all available alternatives; define $S \subseteq A$ as the choice set, u as a nonnegative function that specifies the utility for each aspect, and s as the number of aspects remaining after eliminating the aspects common to all alternatives in the choice set.

Let S_i be the set of alternatives contained in S that exhibit characteristic i, $i = 1.. . s$. Let u_i be the utility scale (or "utility" or "weight") for each characteristic i, $i = 1.. . s$. According to the Luce model (Luce 1959), whenever the alternatives are composed of disjoint aspects, the probability of choosing alternative $a \in S$, with a having characteristic i, is given by:

$$P_S(a) = \frac{u_i}{\sum_{j=1}^{s} u_j} \tag{2.1}$$

As mentioned earlier, the EBA model generalizes the Luce model. Then, according to an EBA decision strategy, with alternatives composed of joint aspects (i.e. more than one alternative exhibit the same characteristic), the probability of choosing alternative $a \in S$ is defined recursively by:

$$P_S(a) = \sum_{i=1}^{s} \frac{u_i}{\sum_{j=1}^{s} u_j} P_{S_i}(a), \tag{2.2}$$

where $P_{S_i}(a)$ denotes the probability that a be chosen from the sets S_i of alternatives having the characteristic i in common, with $i = 1.... s$.

The term $u_i/\sum_{j=1}^{s} u_j$ represents the probability of selecting characteristic $i = 1... s$.

Note that whenever all characteristics are common to all alternatives in S, this simplifies to $P_S(a) = 1/|S|$, where $|S|$ represents the cardinality of S.

One of the key challenges to the use of the EBA model is the difficulty in estimating its parameters. We used the approach by Wickelmaier and Schmid (2004) and developed our own Matlab tool accordingly. The authors propose original methods for estimating EBA in a separate work.

3. Proposed evaluation and decision making framework (TEBA)

In order to formulate the decision framework, a collection of procedures needs to be specified and which defines the following items: decision maker, alternatives, attributes of alternatives, and decision rule (see Ben-Akiva and Lerman, 1985; Ben-Akiva et al., 2002).

Challenges with the current state of literature and practice with regards to evaluation and decision making for transportation investment projects as presented in Section 1 include (1) the absence of a common framework that supports group/collective decision making within which the different stakeholders can make their decision, (2) the absence of accounting and analysis of the differences in perspectives that the different players involved on the project have, (3) the absence of a tool that promotes consultation and identifies consensus, (4) the selection of criteria and the form in which criteria are reported to the decision maker, (5) the implicit compensation across criteria which could mask the real impact of some of the important criteria and the difficulty in soliciting consistent evaluation of relative importance across criteria, and (6) the focus on criteria reflecting a deterministic state of the world. Moreover, the decision rule underlying decision makers' choices is not clear; a deterministic weighing-scoring decision making approach is assumed in most cases.

Accordingly, we propose an evaluation and decision framework that:

1. supports group/collective decision making
2. ensures transparency in the decision process

[2] The formulation of the EBA model presented in this section is based on the work by Anderson et al. (1992).

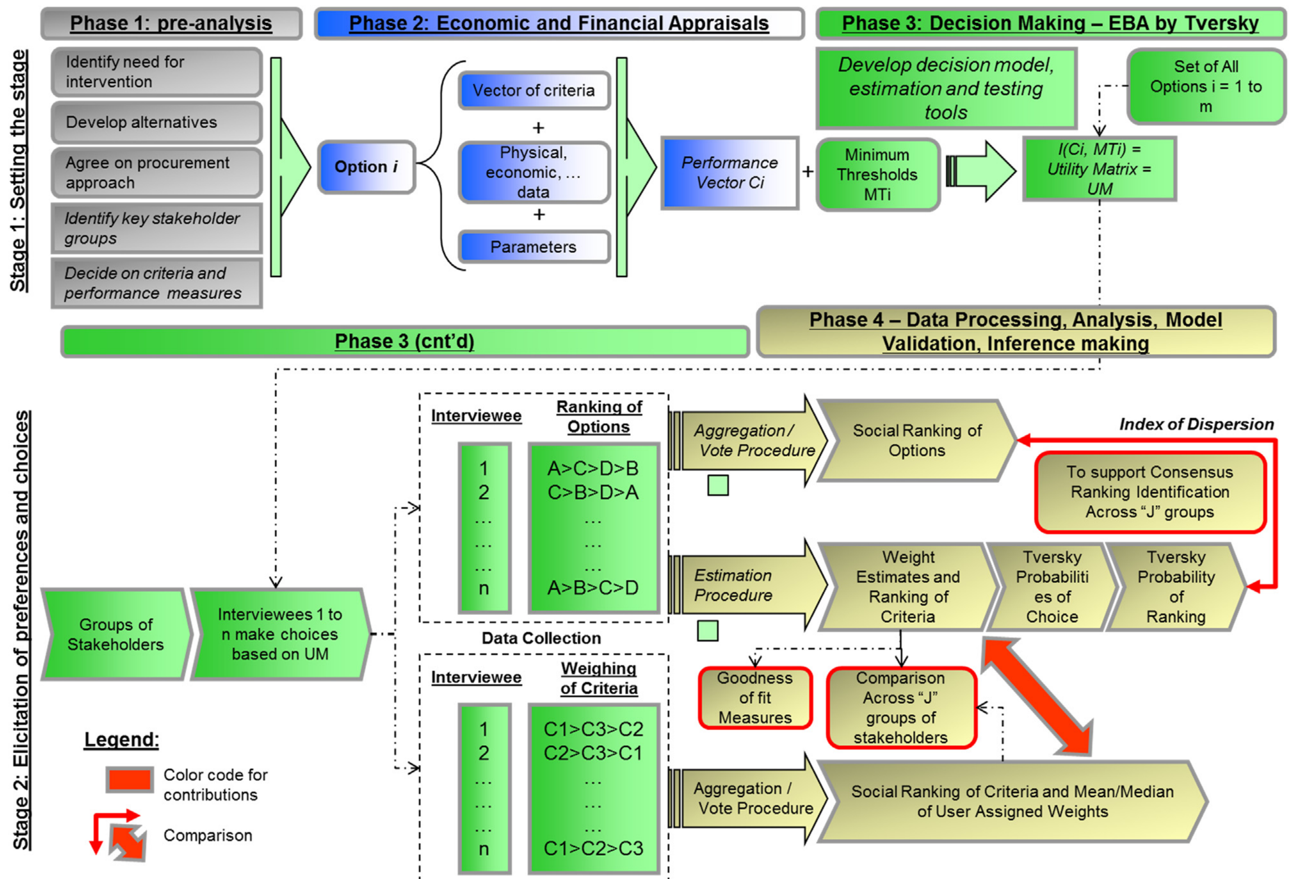

Fig. 3.1. The Transportation Elimination by Aspects framework (TEBA).

3. reflects/ describes the will of the general public (will help in efforts on "consultation") in addition to the more typically observed choices by the public and the private sectors
4. identifies consensus/joint decision across the groups of stakeholders.
5. incorporates different types of criteria from different analyses and represents them efficiently
6. clearly communicates a project's risk return profile to the decision maker
7. overcomes the "compensation effect"
8. uses probabilistic decision theory

The TEBA framework is formulated as an evaluation and decision making framework in the context of transportation investment project selection. It is designed to overcome limitations identified in current frameworks within the aforementioned context. TEBA is not an attempt to replace CBA, but rather takes CBA a step forward. While CBA does not indicate how multi-dimensional preferences may be aggregated, this research proposes one way to do so with TEBA. Fig. 3.1 displays a graphical representation of TEBA.

The TEBA framework is developed to account for perspectives of multiple key identified stakeholder groups, considered in this research to be the Public Sector, the Private Sector and the General Public groups. It considers information from both the economic and financial analyses, introduces separate risk measures, and allows analysis of group reaction to those. The framework adopts an aggregate view of decision making, by group, and generates the social deterministic ranking of options as well as the likelihood of that ranking occurring based on the probabilistic model of choice: the Elimination by aspects model (EBA). It supports consensus reaching across the three groups of stakeholders.

The first phase in the TEBA framework is pre-analysis. At this stage, the need for intervention is identified, alternatives to respond to the need are developed and the set of criteria and performance measures to describe the different options are agreed upon. These are selected based on a review of the literature to reflect a broad range of socio-economic and financial performance. The key stakeholders on the project are identified at this stage too. These are categorized into groups of decision makers that are as homogeneous as possible in terms of their stakes vis-à-vis the project at hand.

The second phase involves the economic and financial appraisals. Each option is analyzed and its performance on each of the measures identified in phase 1 is reported. Evaluation/appraisal and analysis during this stage rely heavily on concepts from CBA theory. One outcome of this stage is a main performance matrix that aggregates the results from phase 2 for all options. Also, performance sub-matrices are defined by selecting and reporting results for a sub-set of the criteria. The performance sub-matrices include three "Analysis Type"(s), namely the Economic Analysis incorporating a mix of socio-economic and financial value measures, the Financial Analysis focused on financial value measures and the Full Analysis focused on socio-economic measures.

In the third phase utility matrices are developed based on performance sub-matrices and data is collected. Collected data includes ranking of options and weight assignment to criteria by decision makers.

The fourth phase includes the methodology to process the data, analyze the results, validate the model and make inferences. Voting procedures are used to aggregate individual rankings of options and criteria and generate the social ranking of options and criteria per group. Three voting theories/procedures (Balinski and Laraki, 2007; Zahid, 2011; Young, 1988; Lippman; Nurmi) were applied:

(1) Plurality wins: only considers first place winners. The number of times each option is selected in rank one is tracked. The option with most rank-one occurrences is the preferred option.
(2) Pairwise wins: every combination of two options in the choice set is identified. The preferred option (winner) in each of the resulting two-options set is tracked. The option that wins most times after considering all combinations of options ranks first. All two-option choice sets that have the rank-one option are removed. The same logic is followed with the remaining combinations of options to select rank-two option and subsequent options rankings.
(3) Borda method: associates with each option a value based on its rank. The option that scores the most is the winning option.

In case of discrepancies, the median rankings were retained.[3] We refer to the ranking from this step as the "deterministic social aggregate ranking".

Individual rankings of options are used to estimate EBA utility scales and generate a Tversky probability of options' ranking. Social ranking of options and Tversky probabilities of ranking are used to validate the EBA model and support consensus ranking identification across the groups. The Index of Dispersion (ID) is developed to determine the likelihood of the deterministic social aggregate ranking and identify a consensus ranking. The Index of Dispersion, for a given sequence, is defined as the sumproduct, over all possible sequences, of the EBA probability of the tested sequence occurring and the step moves separating it from other possible sequences. Further details on the Index of Dispersion are included in Appendix A. The value of the Index of Dispersion will reflect the likelihood of the tested sequence occurring, in our case, the one corresponding to the Deterministic social aggregate Ranking (DR); a low value for the index of dispersion indicates that the sequences with highest probabilities are the ones that are "closest" to the tested sequence.

EBA estimated utility scales are compared across the groups and compared to the social ranking of criteria from direct user weight assignment. Inferences are made with respect to the validity of the model, criteria preferences by group by analysis type, options' preferences by group by analysis type, and possible consensus ranking of options.

In summary, the TEBA framework overcomes the challenges with current frameworks summarized earlier in this section as it (1) provides guidance based on synthesis of the literature for selecting group specific criteria, introduces composite criteria to explicitly account for risk, allows for large numbers of criteria to be presented to the decision maker without impacting the quality or complexity of the decision making process and allows for criteria to be presented in their original most intuitive definitions and unit systems, (2) presents information to the decision maker in a form that does not allow implicit compensation across criteria, (3) uses voting methods alongside with EBA modeling and estimation to assess and validate the weights of the criteria, (4) includes criteria resulting from probabilistic analysis accounting for input uncertainties, (5) supports decision making by multiple stakeholder groups, (6) allows the independent analysis of the differences in perspectives on options ranking as well as criteria importance that the different players involved in the project have, and (7) defines the index of dispersion and social aggregate rankings to provide a methodology for promoting consultation and identifying consensus. Moreover, TEBA investigates and is designed to uncover the decision rule underlying decision makers' choices.

The methodology, and the underlying tools and methods are demonstrated in detail in a case study. The case study features 6 options for providing a land connection between Beirut and Damascus. It involves 3 groups of decision makers: the Public sector, the Private sector and the General public. Each group is presented with utility matrices with 7 criteria; criteria are group specific. More details are presented in the next section.

4. TEBA empirical case study

4.1. Demonstrating the methodology

Best practices from the reviewed literature on project evaluation and concepts from the TEBA framework were applied in developing the case study. The case study will reflects the four phases of TEBA.

4.1.1. TEBA Phase 1: pre-analysis; identify need, develop alternatives, agree on procurement, identify stakeholders, and decide on decision criteria

The case study deals with the land connection between Beirut and Damascus. The current road section between the two capital cities is highly congested and is frequently the scene of severe accidents. The two capitals are separated by 2 chains of mountains and are approximately 100 Km apart. The need for an enhanced connection has long been established.[4]

Technically feasible project options were developed by the authors by generating concept designs of route alignments and estimating corresponding bills of quantities. An approximation of the topographical conditions was done based on the experience of the authors with the Lebanese terrain as well as through consultation with other experts who have extensive knowledge of the region. Unofficial price quotations were obtained from active consulting firms and cost estimates were calculated accordingly. A Public Private Partnership with a BOT arrangement was identified by the authors as a preferred procurement approach to simplify the demonstration of TEBA concepts. Table 4.1 provides a summary of the options and of the rationale behind each of them:

It is generally noted that several groups of stakeholders are involved or at least concerned with the decision regarding the investment in transportation projects: investor, owner, technical actors, administrative actors, the public, non-governmental organizations, politicians and legal actors (Cundric et al., 2008;, Salling and Banister, 2009). Particular care should be given to the choice of the stakeholders. For the purpose of demonstrating the TEBA methodology in this case study, we regroup stakeholders under different categories and map out as in Fig. 4.1 the influence, objectives and drivers of the various groups based on a synthesis of the literature in Khraibani (2012). The authors then group stakeholders in 3 major groups deemed representative of the overall structure shown in Fig. 4.1: the Public Sector, The Private Sector, and The General Public. Other stakeholders may need to be taken into account, and the choice of such stakeholders could play an important role in the analysis. In this paper, the authors are proposing a particular methodology that considers input from

[3] Example: Options A, B, C, D, E, F rank 6, 3, 5, 1, 2, 4 based on plurality wins approach, 6, 3, 4, 1, 2, 5 based on the pairwise wins approach and 6, 3, 5, 1, 2, 4 based on Borda scores, then the median ranking is 6, 3, 5, 1, 2, 4.

[4] This research was started prior to the conflicts in Syria and the case study and surveys were conducted right before the onset of the conflicts. The analysis in the case study therefore assumes normal conditions governing the decision making (not a force majeure environment).

Table 4.1
Case study: alternative project options' description summary and rationale.

	Option description summary	Option rationale summary
Option 1	Maintenance and rehabilitation of existing highway and indirect Toll, 110 Km	Simplest intervention.
Option 2	New toll highway, no structures, 110 Km, all weather	Serves destinations along the route. Longer, curvier alternative. Lower total cost in the absence of structures and low uncertainty around the cost.
Option 3	New toll highway, structures intensive, 90 Km, all weather	Supports travelers to destinations along the route. Optimized alignment for quality of ride and time saving. High cost and cost uncertainty.
Option 4	High Speed Rail (HSR) with minimum structures and no intermediate stops, 100 Km, speed >200 Km/hr	Non-stop rapid access between the cities. Limited investment in high cost structures reducing the uncertainty around capital cost.
Option 5	Regional Non-High Speed Rail with minimum structures and 2 intermediate stops, 145 Km, runs at 60 to 120 Km/hr using the ROW of the existing Railway track	Serves travelers to intermediate regions. Follows existing old rail route. Low service cost.
Option 6	HSR along shortest path with major structural work, no intermediate stops, 90 Km	The "Concorde" rail alternative. High cost of service. Directed for business and point to point travelers.

different stakeholder groups; the empirical case study is to be considered as a "proof-of-concept" for the proposed methodology, and therefore the stakeholder groups that were considered may not have been comprehensive. Nevertheless, the General Public group proposed in TEBA may encompass different groups that are mentioned in the literature and encountered in real life applications. In future development of the research and in real life applications, the online survey would be shared with a wider range of potential stakeholders and the increased number of respondents will only improve the quality of TEBA analysis and conclusions.

Furthermore, 14 criteria were chosen to cover a range of socio-economic and financial value measures as well as risk measures, and were aggregated differently in 3 tables. The selection of the criteria was based on a thorough review of the literature covering various evaluation methods and most commonly used criteria. Some of the criteria are extensions to what is found in the literature, such as the combined Financial NPV and Standard deviation criterion. Some other criteria are less commonly used in the literature but are tested here to overcome what was seen as a gap in the current literature, such as the Financial NPV-at-Risk. Furthermore, a synthesis of the literature supported the choices of which criteria to present to which groups of stakeholders. For instance, while the public sector is not typically looking for financial profits especially under a BOT arrangement, it could still contemplate the financial risk/return profile to understand if the private sector partner is taking too much risk and if it expects returns that will motivate proper performance (de Palma et al., 2013). For a complete discussion of most commonly used criteria and the logic behind the selection of the 14 criteria for this work, the reader is referred to Khraibani (2012). Table 4.2 summarizes the list of criteria by group.

4.1.2. TEBA phase 2: economic and financial appraisals; develop the performance matrix

For the case study at hand, the results of the financial and socio-economic analyses are presented in performance matrix form in Table 4.3: There is no clearly dominating option. That is, it is not readily clear that any of the six options should be chosen as a winning alternative to proceed with.

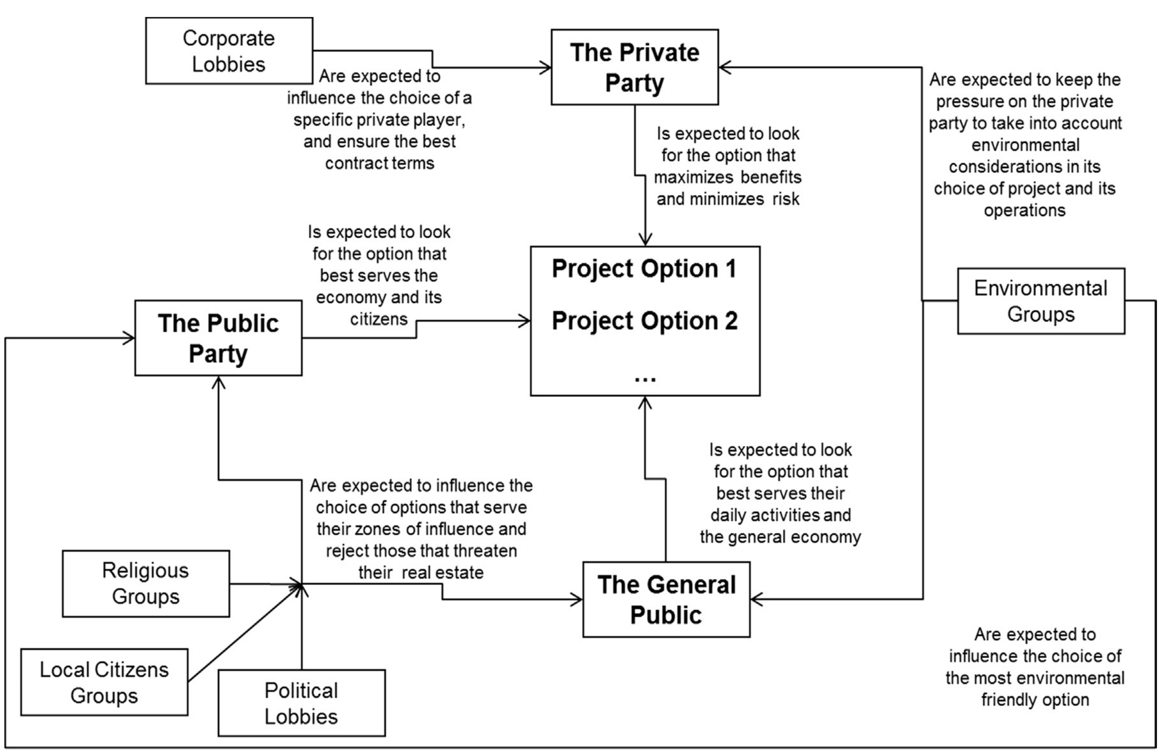

Fig. 4.1. -Standpoints of different stakeholder and decision making parties – Case study: Beirut–Damascus land connection.

Table 4.2
List of criteria by type and by group of respondents – Case study: Beirut–Damascus land connection.

List of all criteria (Cr.)	Economic Cr. (communicated to the Public Sector)	Financial Cr. (communicated to the Private Sector)	Combined set of Cr. (communicated to all groups)
Expected value of socio-economic NPV (benefits include savings in TT, VOC, and Accidents/Deaths)	X		X
Socio-Economic NPV-at-Risk (benefits include savings in TT, VOC, and Accidents/Deaths)	X		X
Number of deaths or near-deaths causing from accidents per year	X		
Absolute travel time on key travel segment in hours	X		X
Impact on employment-scale is 1 to 10; 10 is best	X		X
Impact on accessibility of the Poorer-Scale 1 to 10; 10 is best	X		
Environmental friendliness (including carbon emissions, noise levels, cuts in forests, …)-Scale is 1–10 where 10 is best	X		
Financial IRR base case value		X	
Financial IRR expected value		X	
Financial NPV base case value		X	
Financial NPV expected value and standard deviation		X	X
Financial NPV-at-Risk		X	X
PV Initial Investments expected value (MT defined within a range)		X	
Payback period expected value		X	X

From the global performance matrix we define three subset performance matrices regrouping the criteria as described in the top row of Table 4.2. The first performance matrix includes only the socio-economic criteria (PM1), the second includes only the financial criteria (PM2) and the third includes a combination of those (PM3).

4.1.3. TEBA phase 3: EBA decision making; setting minimum thresholds, developing utility matrices, conducting interviews, collecting ranking data for options and criteria

Then, EBA was adopted as the decision model and MT vectors were defined corresponding to each performance matrix. Some criteria such as “Financial NPV Expected Value and Standard Deviation” are composite criteria and two thresholds, also assigned by experts, were used accordingly. Double bound thresholds for some other criteria such as “PV Initial Investments Expected Value (MT defined within range)” were used.

The resulting utility matrix was generated for each performance matrix. Table 4.4 shows the Economic Utility Matrix, UM1 resulting from MT1 and PM1.

UM1 was used by the decision makers in the Public Sector subgroup to make choices on preferred alternatives. Similarly, utility matrices for the other sub-groups were generated from a distinct grouping of the criteria. The utility matrices were communicated to the decision makers through an online survey.

All options were presented at first in the survey. The interviewee was then asked to make a choice of a preferred option among the available options. Once a choice is made, that option was removed from the set of available options and the utilities matrix now had one less option. The interviewee was asked to choose a preferred option from the updated reduced set of options. This was repeated until all options were exhausted. This same process was conducted for the different utility matrix types, i.e. this same process was applied with the interviewee being presented (separately) with the financial utility matrix, the economical utility matrix and the combination/general utility matrix. This represented one ranking event for a given utility matrix type. Afterwards, the interviewee was given the chance to provide his own set of MT values. Finally, the interviewee was asked to assign a weight to characteristics on a scale from 1 to 10. This concluded the survey and information from this last section was used to calibrate model results.

4.1.4. TEBA phase 4: data processing and analysis, model validation, inference making

Voting theory principles were employed to conduct a deterministic analysis of the responses of interviewees with respect to alternatives and criteria as described in Section 3.

The deterministic social aggregate ranking of options is generated accordingly. For each group and each corresponding relevant analysis type, assuming no heterogeneity within the group, EBA was investigated as a probabilistic model of choice governing the selection and ranking of preferred options. The value of the Index of Dispersion (ID) reflects the likelihood of the tested sequence occurring, in our case, the one corresponding to the Deterministic social aggregate Ranking (DR). The case for the Public Sector responding to the Economic Analysis DT1 is presented for illustrative purposes. The distribution of the IDs for all sequences is presented in Fig. 4.2. A beta distribution fits the data with an acceptable A–D (Anderson–Darling) coefficient of 0.091.

The 5th percentile value from the distribution shown above is 4.19. It follows that sequences with an index of dispersion lower than 4.19 have a 95 percent likelihood of being generated by the model. The 5th percentile value is referred to as the Cut-off point. Models that return an Index of Dispersion for the social deterministic aggregate ranking below the cut-off point are validated.

For the illustrative case of the Public Sector responding to the Economic Analysis in the case study, Table 4.5 presents the sequence generated from the social deterministic aggregated ranking and the corresponding calculated probability and Index of Dispersion.

With an index of dispersion of 3.03, it is highly likely (more than 95% chance) that the EBA model will reproduce the social deterministic aggregate ranking generated using standard voting theory. This validates the fit of the EBA model in this application.

A consensus ranking is identified by determining the sequence of options that has the lowest “joint likelihood”. In other words, the sequence that has an ID below the cut-off ID for the three stakeholder groups, if it exists, is designated as the consensus sequence.

4.2. Results and key insights

4.2.1. Options results

The deterministic social aggregate rankings (the median ranking from the application of the three voting theory rules described

Table 4.3
Performance matrix for the case study; analysis by authors – input for the analysis compiled from publicly available information and data from experts. The parts of the table highlighted in lighter orange reflect results from the Economic Analysis while those highlighted in darker orange reflect results from the Financial Analysis as defined in Table 4-2.

Alternative/ option	Criterion														
	Financial IRR Base Case Value	Financial IRR Expected Value	Financial NPV Base Case Value (in million $)	Financial NPV: Expected Value (EV) and (EV-Standard Deviation) (in million $)		Financial NPV-at-Risk (in million $)	PV Initial Investments Expected Value (MT defined within range) (in million $)	Payback period Expected Value (in years)	Expected Value of Socio-Economic NPV (benefits include savings in TT, VOC, and Accidents) (in million $)	Socio-Economic NPV-at-Risk (benefits include savings in TT, VOC, and Accidents) (in million $)	Number of deaths or near-deaths per year from accidents	Absolute travel time on key travel segment in hours	Impact on Employment-Scale is 1 to 10 where 10 is best	Impact on Accessibility of the Poorer-Scale is 1 to 10 where 10 is best	Environmental friendliness (Including carbon emissions, noise levels, cuts in forests, …)-Scale is 1 to 10 where 10 is best
Option A	10.3	10.5	2	2	−6	−12	61	11.3	221	123	100	1.4	1	1	1
Option B	12.2	12.4	149	174	−5	−90	517	12.6	1227	712	20	1.1	9	7	9
Option C	10.6	8.4	93	−222	−557	−790	1234	17.5	1384	244	15	0.9	7	6	6
Option D	13.1	12.4	483	418	−25	−205	1118	13.5	528	88	5	0.7	6	5	9
Option E	12.6	13.6	314	517	−19	−150	878	12.7	3599	2036	5	1.4	7	9	7
Option F	15.1	12.3	900	474	−302	−641	1322	14.4	384	−397	5	0.5	9	4	6

earlier) that resulted from each of the groups/decision table combinations are distinct as presented in Table 4.6.

Based on both deterministic results, groups will rank options differently when provided with different or identical sets of criteria, confirming the need for noting the 3 perspectives and identifying a consensus mechanism.

The results from testing the EBA model under no heterogeneity assumptions for the deterministic social aggregate ranking by group are presented in Table 4.7.

4.2.2. *Consensus analysis*

Based on the social deterministic aggregated rankings by the 3 groups of stakeholders making decisions based on group specific analyses, as reported in Table 4.1, a sequence of options that is representative of the preferences of all three groups could not be identified. For all three groups making decisions based on group specific analysis, an EBA model was provided, accepted, and validated. Accordingly, the index of dispersion for any sequence can be identified from each of the resulting 3 EBA models. As noted earlier, rankings that return an index of dispersion below a pre-defined cut-off point for a given EBA model have a high likelihood and are therefore rankings that are highly likely to be a preferred outcome of the model. The ranking that has IDs lower than the cut-off point for the EBA models of the 3 groups of stakeholders and that has the lowest sum of the IDs across the three groups is considered the consensus sequence. Table 4.8 displays the ranking identified as the consensus ranking as well as information on the ranking generated from applying the Borda rule to the three deterministic rankings from Table 4.6. The latter has one of the lowest sum of ID's but does not meet the 5th percentile ID cut-off limit for both the Private Sector and the General Public. While the consensus ranking has a slightly larger sum, it does meet the 5th percentile ID cut-off for all three groups. Also, the sum of ID's is in the top 1.5% of sums of IDs across all 720 ranking combinations.

The consensus ranking identified based on the EBA analysis is therefore one that is highly likely to reflect/satisfy the choices/preferences of all three groups.

4.2.3. *Criteria results – weights analysis*

The respondents in each group assigned weights to criteria from relevant analyses. Those weights reflect the importance of each criterion on a scale from 1 to 10. The medians of those weights by group by analysis type are presented in Table 4.9.

For the three combinations of groups and analysis types for which the EBA model was found to be highly significant, the parameters of the EBA models by group by analysis type are presented in Table 4.9. Those parameters are the EBA utility scales described in Section 2.

Deterministic weight assignment seems to attenuate the difference in weights across the criteria, especially for the Public Group. For instance, averages of weights assigned by the Public Sector to the seven criteria in the Economic Analysis span the narrow range of 0.78–1 with an average of 0.88 and a standard deviation of 0.09.

EBA weights distribution suggests that only 3 to 4 criteria are key to reaching a decision. For instance, for the Public Sector making decisions based on the Economic Analysis and the Private Sector making decisions based on the Financial Analysis, weights/utility scales estimated from the EBA model of each combination reveal that there is an 84% and 82% chance, respectively, that the top 3 criteria would be selected as criteria for elimination. In other words, in more than 80% of the cases, the elimination of options will be conducted based on the top three criteria.

4.2.4. *Criteria results – ranking analysis*

The results of ranking of criteria resulting from the two approaches are then investigated. Consistency in criteria ranking was

Table 4.4
Utility matrix UM1, Economic Analysis.

Alternative/option	Criterion						
	Expected Value of Socio-Economic NPV (in million $)	Socio-Economic NPV-at-Risk (in million $)	Number of deaths or near-deaths per year from accidents	Absolute travel time on key travel segment in hours	Impact on Employment-Scale 1 to 10; 10 is best	Impact on Accessibility of the Poorer-Scale 1 to 10; 10 is best	Environmental friendliness-Scale 1 to 10; 10 is best
MT1	500	100	10	1	9	9	9
Option A	0	1	0	0	0	0	0
Option B	1	1	0	0	1	0	1
Option C	1	1	0	1	0	0	0
Option D	1	0	1	1	0	0	1
Option E	1	1	1	0	0	1	0
Option F	0	0	1	1	1	0	0

generally acceptable. These results are presented in Table 4.10. Cells shown in similar colors indicate ranking positions that were close to tie.

Consistency across deterministic and EBA estimated rankings of criteria is noted for top 2 to 3 criteria. Also, the ranking of top criteria across groups is consistent with what the authors expected based on the literature review. The public sector ranks the expected value of the socio-economic NPV at the top. The private sector ranks first the financial NPV expected value and (expected value – standard deviation). The general public cares most about travel time.

4.2.5. Minimum thresholds analysis

Fig. 4.3 presents the MT distributions for all 3 groups for criteria in the Full Analysis.

Plots of the minimum threshold (MT) values input by the decision makers reveal an increasing risk perception with increasing criterion importance. For instance, the private sector's distribution of MTs for the Financial NPV EV is most shifted to the right while the Payback period for that same group is most shifted to the left. The private sector puts higher constraints on these 2 profit driving criteria. The general public is clearly on the opposite side with MTs reflecting lower financial expectations from the project.

Table 4.5
Index of dispersion for aggregated social rankings.

	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6
Median ranking from aggregation methods	D	E	B	F	C	A
Index of dispersion	3.03					

4.3. Discussion of results and key insights

The EBA model does explain the choices made by groups in the context defined in this work. It also supports the identification of a sequence of options with highest likelihood across the three groups resulting in a “consensus” sequence.

As expected, even when faced with the same set of information (the Full Analysis), groups' choices of options are not the same.

The MT values assigned by the three groups to criteria in the Full Analysis revealed an increasing risk aversion with increasing

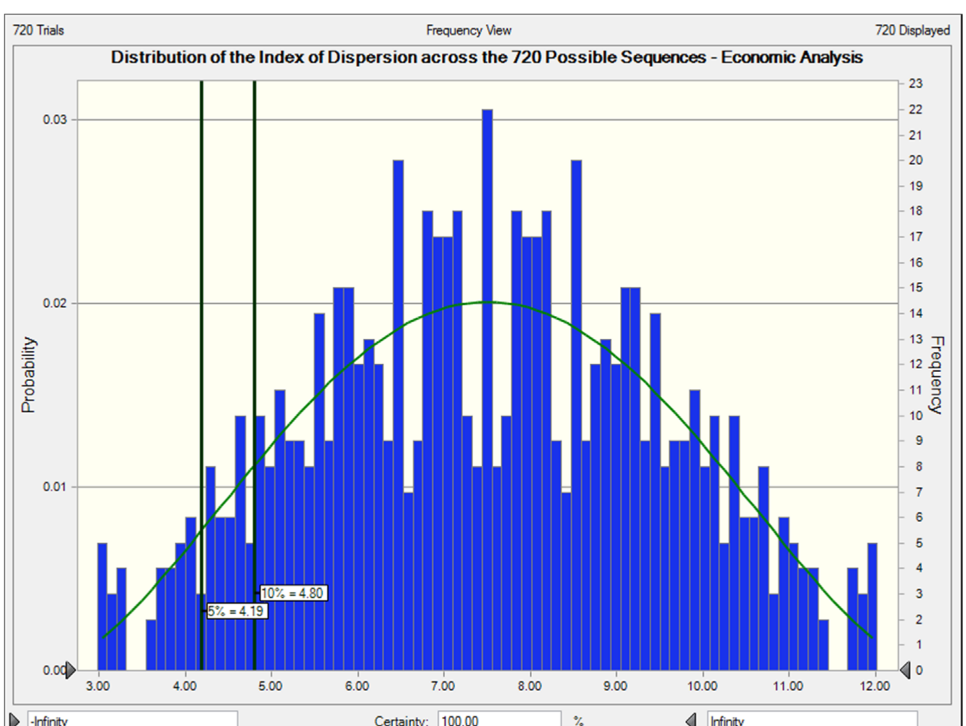

Fig. 4.2. Distribution of the index of dispersion across all possible sequences for results from the Economic Analysis.

Table 4.6
Deterministic social aggregated rankings by group and analysis type.

Group	Analysis	Option ranking					
		Option A	Option B	Option C	Option D	Option E	Option F
Public	Eco	6	3	4	1	2	5
Private	Fin	5	2	6	3	1	4
General	Full	6	3	5	2	4	1
ALL	Full	6	3	5	1	2	4
Public	Full	5	2	4	3	1	6
Private	Full	3	4	6	1	2	5

Table 4.7
Summary of EBA models testing results, by group and analysis type.

Group	Analysis type	Chi-square	*p*-Value	Index of dispersion		EBA is:
				Cut-off@5th percentile	Ranking ID	
Public	Eco	4.8	>0.1	4.2	3.03	Accepted
Private	Fin	8.6	>0.1	4.2	2.93	Accepted
General	Full	3.48	>0.1	6.8	6.82	Accepted

Statistical tests, including (1) *p*-values >0.1 and (2) Indices of Dispersion for a group's winning ranking below the cut-off Index of dispersion for that group, indicate that it is highly likely that stakeholders have employed EBA in making decisions.

importance of the criterion. It also revealed a tendency to be more "demanding", or stringent, with respect to criteria that matter most, with the group that cares most about a criterion assigning the most constraining minimum threshold value.

Averaging of absolute values of weights assigned by users yielded unsatisfactory results. This is a result of "attenuation effect" from averaging weights across the responses of the groups' members. In the particular case of the Public Sector, this was further traced back to a biased tendency on the side of the interviewee to a concentrated use of the 5–10 range of the 1–10 scale. On the other hand, the rankings of criteria resulting from the weights assignment yielded results significantly in-line with expectations. We therefore adopt ranking comparison of criteria rather than weights comparison.

It is interesting to note that both the public sector and the general public had a similar particular interest in the criterion Impact on Employment. In fact, results from the deterministic analysis and from the EBA model estimation indicate that the most important criterion to each of the groups was exactly as expected and discussed in the literature and in practice. The private sector cares first and foremost about financial value and risk, the public sector first looked into economic value and risk while the first concern for the general public was travel time.

For a more elaborate and detailed discussion of results and data from the case study the reader is referred to Khraibani (2012) which contains some more complete accounting of the results. At the same time, the authors would like to emphasize the fact that the case study is meant as a proof-of-concept for the proposed framework and methodology. The observations made in the policy analysis section reflect the type of conclusions that may be made based on the proposed methodology, and some of them may not be generalizable beyond the case study context.

4.4. Survey notes

The interviewees were also requested to make an explicit statement at the end of the survey describing the approach they followed while making choices on preferred options along the survey steps. Amongst those who replied, not surprisingly, a group mentioned a compensatory approach similar to a basic linear additive approach, basically favoring the options whose total score based on addition of criteria weights was highest. On the other hand, another group outlined a non-compensatory lexicographic approach whereby options that did not meet their most important criteria were eliminated sequentially. There was therefore a veto component to their decision. The hypothesis that the EBA model can explain the decision process governing the choices made within the TEBA framework is therefore worth further investigation.

For more details about the survey, including more information on the web-survey steps, the architecture of the data input from the web-survey, survey timeline, choice of target groups/respondents, and distribution of respondents, data processing and estimation platform, the reader is referred to Appendix B.

5. TEBA for policy making

This work presented a new evaluation and decision making framework (and methodology) for large transportation projects to elicit, structure and quantify the aggregation of the preferences over project alternatives of three types of stakeholders, the TEBA framework. It tested and provided a proof-of-concept for the proposed framework using a case study designed for this purpose

Table 4.8
Testing the proposed synthesized sequence from deterministic aggregation.

Selected rankings	ID Eco	ID Fin	ID Full	Meets ID cut-off f or Eco=4.2 @ 5%?	Meets ID cut-off f or Fin=4.2 @ 5%?	Meets ID Cut-off for Full=6.8 @ 5%?	Sum of IDs
D > E > B > F > C > A*	3.0	4.6	6.9	Yes	No	No	14.51
D > B > E > F > A > C**	**4.0**	**4.0**	**6.7**	**Yes**	**Yes**	**Yes**	**14.70**

* Ranking generated from using Borda rule to deterministic rankings by three groups (refer to Table 4.6).
** Ranking with lowest sum of IDs (1.5th percentile) while meeting 5th percentile ID cut-off for all three groups.

Table 4.9
Weights of criteria based on deterministic aggregation vs EBA estimation.

Median of deterministic assigned weights and point estimate from EBA model								**Mean Across Criteria Det. Weights**	**Strd. Dev. Across Cr. Det. Weights**	**Prob. of Select. of Top 3 Criteria**
Public-Eco										
Criterion	E(ENPV)	ENPV-at-Risk	Nb of deaths or near-deaths	Absolute travel time	Impact on employment	Impact on accessibility of the poorer	Environmental friendliness			
Assigned	1.00	0.78	0.88	0.79	1.00	0.88	0.83	0.88	0.09	
EBA	1.00	0.15	0.40	0.08	0.21	0.00	0.09			84%
Private-Fin										
Criterion	Financial IRR Base Case Value	Financial IRR Expected Value	Financial NPV Base Case Value	Financial NPV: (EV) and (EV-SD)	Financial NPV-at-Risk	PV Initial Investments Expected Value	Payback period Expected Value			
Assigned	1.00	1.33	1.00	1.67	1.17	1.00	1.00	1.17	0.25	
EBA	1.00	0.62	0.35	2.98	0.39	0.00	0.24			82%
General-Full										
Criterion	Financial NPV: (EV) and (EV-SD)	Financial NPV-at-Risk	Payback period Expected Value	EV of Socio-Economic NPV	Socio-Economic NPV-at-Risk	Absolute travel time	Impact on Employment			
Assigned	1.00	1.20	1.33	1.63	1.75	2.00	2.42	1.62	0.49	
EBA	1.00	0.04	0.97	0.44	0.56	1.46	0.80			65%

and communicated to stakeholders through an interactive online survey. This paper also demonstrated the use of the TEBA framework as a tool to reach consensus on projects' ranking by identifying the ranking with highest likelihood across all stakeholder groups, given that the likelihoods are significant. In addition, this paper demonstrated the use of an individual decision model, EBA, for group decision making. It also demonstrated the use of a non-compensatory choice model for transportation infrastructure investment decisions. The use of combined criteria and two sided thresholds in the context of EBA is another contribution.

More specifically, the TEBA framework was shown to overcome the challenges laid out in Section 3 as it (1) supported group/collective decision making, (2) used deterministic voting methods alongside with EBA modeling and estimation to assess and validate the weights of the criteria, (3) was validated as a framework for multiple stakeholder groups and allowed the independent analysis of the differences in perspectives on options ranking as well as criteria importance that the different players involved on the project had, including the General Public, (4) defined the index of dispersion and social aggregate rankings to provide a methodology for promoting concentration and identifying consensus, (5) provided guidance based on synthesis of the literature for selecting group specific criteria, introduced composite criteria to explicitly account for risk, allowed for large numbers of criteria to be presented to the decision maker without impacting the quality or complexity of the decision making process and allowed for criteria to be presented in their original most intuitive definitions and unit systems, and (6) presented information to the decision maker in a form that does not allow implicit compensation across criteria while focusing on criteria resulting from probabilistic analysis accounting for input uncertainties. Moreover, TEBA investigated and successfully uncovered using econometric methods the decision rule underlying decision makers' choices to be a probabilistic non-compensatory model of choice.

Key results from the case study showed that it is highly likely that stakeholders have employed EBA in making decisions. Results also highlighted distinct rankings of options by the different stakeholder groups; the EBA model supported identification of a consensus ranking of options. Results also suggest that the most important criterion for every group based on EBA utility estimates was consistent with the expectations based on the literature review and the EBA analysis suggested that only the top 3 to 4 criteria are significant in reaching a decision. Furthermore, aggregation of deterministic user assigned weights attenuated differences across criteria for some of the groups and analysis of user assigned weights. MT values suggested higher risk perception with increased criterion importance.

Policy implications are generated accordingly. It is recommended to reach out to key stakeholders and request their direct input on decision making in the aforementioned context and reduce the role of "experts" in decision making. The role of experts should be limited to the performance appraisal stage and to setting Minimum Thresholds where applicable. Minimum threshold values should be cross checked with distributions of MTs solicited from the various decision makers. MT vectors should be tailored for each group. Also, the decision making should be modeled in a probabilistic framework rather than a deterministic "one score" approach. The project owners should seek to identify a consensus ranking of available options that reflects the preferences of the key stakeholder groups involved in the process. This is a ranking that is likely enough to result from each group's choices. Moreover, particular attention should be placed on determining the values of the criteria that emerged as "top" at the evaluation stage. Along the same lines, it appears that there is preliminary evidence that "expected values" of performance measures have higher worth than base case values to decision

Table 4.10
Ranking of criteria based on deterministic social aggregation vs ranking of criteria from EBA weights estimation.

Criteria ranking (criteria with same highlight color refer to criteria that were in tight competition for a rank)								Consistency of criteria importance ranking
Public-Eco								
Criterion	E(ENPV)	ENPV-at-Risk	Nb of deaths or near-deaths	Absolute travel time	Impact on employment	Impact on accessibility of the poorer	Environmental friendliness	
Assigned	1	7	2	6	3	4	5	Acceptable
EBA	1	5	2	6	3	7	4	
Private-Fin								
Criterion	Financial IRR Base Case Value Value	Financial IRR Expected Value	Financial NPV Base Case Value	Financial NPV: (EV) and (EV-SD)	Financial NPV-at-Risk	PV Initial Investments Expected Value	Payback period expected value	
Assigned	6	2	5	1	3	4	7	Acceptable
EBA	3	2	4	1	5	7	6	
General-Full								
Criterion	Financial NPV: (EV) and (EV-SD)	Financial NPV-at-Risk	Payback period Expected Value	EV of Socio-Economic NPV	Socio-Economic NPV-at-Risk	Absolute travel time	Impact on employment	
Assigned	4	5	7	3	6	1	2	Acceptable for top criteria
EBA	2	7	3	5	6	1	4	

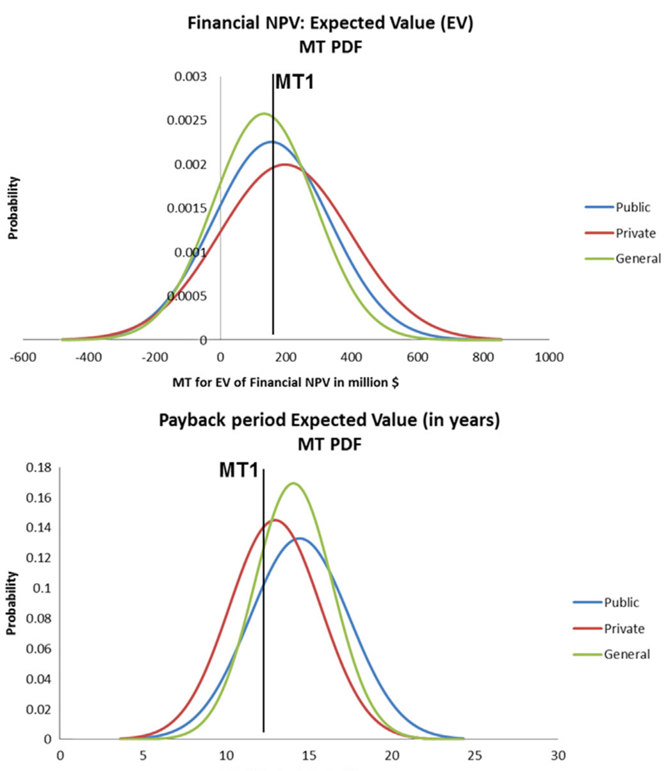

Fig. 4.3. MT Probability distribution functions for criteria in Full Analysis matrix, based on values assigned by the 3 stakeholder groups.

makers. Also, risk measures proved important to decision making by the Private sector. Decision makers should refrain from direct assignment of relative weights and an increase in awareness with respect to the importance of these measures for the Public Sector and General Public groups is recommended. In particular, the Value-at-Risk measures should be included in the set of key criteria as an effective measure of risk.

At the framework formulation level, it should be noted that the three groups investigated are not necessarily extensive. The set of criteria that was investigated was based on a thorough analysis of the literature but is not extensive either. Moreover, the information made available in the decision tables of the TEBA framework does not guarantee the selection of the "optimal" option. This is related to the fact that the decision tables only indicate a one-bounded MT in general EBA models. It is believed that this may be remedied by indicating two sided MTs. An example on this was the use of a lower bound and an upper bound for the PV Initial Investments Expected Value referred to as EV(PVinvest) criterion; only options that had an EV(PVinvest) that falls between the two boundary values were reflected with a 1 in the utility matrix.

With respect to the case study, it should be noted that it treated the case of a project in Lebanon, a third world country, and a large proportion of the stakeholders were from Lebanon. Also, the case study featured strictly land transportation options. Moreover, it did not account for the effect of freight transportation. Also, the sample size was limited but produced statistically significant results. The framework and the approach were tested for the first time in this work. Accordingly, further testing and applications are required and results are not readily generalizable at this stage.

The key direction for extending this research is to investigate a compensatory discrete choice model in a context similar to the one described in this work. Comparing the results of this proposed analysis to the ones concluded from this work can be undertaken. One other possible line of research to extend along is the groups of stakeholders we investigate.

Acknowledgments

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Appendix A. – index of dispersion

Before proceeding with the definition of the index of dispersion, a few definitions are in order.

A ranking is an ordering of the options referring to each option's position with respect to the others. A sequence is an ordering of the options where each option is located in its rank position. For instance, the ranking described as: option B is ranks first, option A ranks second and option C ranks last, results in the sequence B>A>C. One could also refer to an option by a number (for example, option A is referred to as 1, option B as 2, etc…) and the position of the option indicates its ranking. So for the same example ranking, the resulting sequence can equivalently be expressed as 2 >1 >3. This latter convention turns out useful for modeling purposes.

Each sequence/ranking of options has a probability of occurring, equal to the probability of each option in the sequence being selected out of a set that contains that option and all the options that rank lower than this option. For instance, the probability of sequence B >A >C occurring is equal to $p=x^*y$, where x is the probability of choosing Option B out of a group containing Options A, B and C, and y is the probability of choosing Option A out of the reduced set of options containing Options A and C. Arguments that the fact that B>{A,C} provides no information have arisen in advanced discussions on the topic. This is a difficult question that we do not deal with in this text. For a discussion of the matter please refer to de Palma and Kilani (2015).

Our choice group contains 6 options, so there are 720 (which is 6!) possible sequences. For each sequence, the probability of occurrence can be calculated from the criteria weights estimated from the EBA model. A Matlab function was developed to calculate the probability of occurrence of each sequence and returns a vector with 720 probability values. These values sum to 1.

Also, each sequence is different from another sequence by a certain number of 1 step moves. For instance, to go from sequence 2>4>1>3 to 1>2>3>4 the minimum number of 1 step moves is 3. The number of 1 step moves is obviously an indicator of the “distance” that separates 2 sequences. This method was also used in de Palma et al. (2011).

We define the Index of Dispersion for a given sequence (the tested sequence) for a given model as the sumproduct of the probability of a sequence in the set, as determined from the EBA model, and the number of steps required to get from this sequence to the tested sequence, over all possible sequences other than the tested sequence. Its value will reflect the likelihood of the tested sequence occurring. A low value for the index of dispersion indicates that the sequences with highest probabilities are the ones that are “closest” to the tested sequence. In fact, the more different a sequence is from the target sequence the higher the number of single steps to go from one to the other and the more it will penalize the index of dispersion. If the probability of this sequence is high and its number of steps is also high then there is a high penalty on the index of dispersion. If the probability of this sequence is low then the penalty is low. On the other hand, if the number of steps is low, that is the sequence is quite similar to the target one, and its probability is high, then that high probability will not have a large penalizing multiplier effect on the index of dispersion.

For the purpose of our work, the tested sequence is the one corresponding to the deterministic social aggregate ranking (DR). Based on the above discussion, the lower the index of dispersion of DR the more likely it is that the EBA model will return DR.

Since the absolute measure of the Index does not allow judgment on whether it is low enough, the relative magnitude of this Index with respect to Indices generated from all other sequences is contemplated.

In other words, sequentially, over all sequences, each sequence is set as the tested sequence and its Index of Dispersion is calculated. There are then 720 indices of dispersion each corresponding to a tested sequence. It is worth mentioning here that we consider a linear distance while we could also consider a quadratic one. The impact of using the latter is proposed as subject for further research.

Appendix B. – survey and data collection

The survey was conducted online. The link to the survey was communicated to carefully selected groups of people through email. Follow-up emails were needed in many cases to ensure the proper administration of the survey. In-person meetings were also conducted to facilitate the process and ensure clarity. The importance of quality answers was emphasized with each individual taking the survey. This was a completely voluntary exercise which leads to belief there is no motive for respondents to provide subquality answers. A comments section at the end of the survey required survey takers to describe qualitatively their approach to decision making and contemplation of the answers to this section by the authors helped confirm the quality of the survey answers. Moreover, consistency of findings from analysis with the state of the literature particularly with regards to criteria preferences by various groups of stakeholders confirms the good quality of the answers.

In the case of the public sector (Group 1), the sub-groups included:

- Members of parliament, Members of parliament and members of infrastructure chamber, Current and former Ministers, Executives in the Ministry of Transportation, Other politicians,
- Advisors to politicians including Ministers and other, Private advisors to the Ministry of Transportation, i.e consulting firms supporting the public sector
- Graduate students (mostly Economics and Civil Engineering students and graduates) at major local and international universities who will potentially pursue careers in public sector advising

In the case of the private party (Group 2), the sub-groups included:

- Professional decision makers in large infrastructure conglomerates
- MBA students and graduates at top-tier universities
- Professional decision making advisors from top Management and Strategy Consulting Firms

The “People's Committee”/General Public (Group 3) included:

- Graduate students at top universities in Lebanon in the domains of

○ Engineering management
○ Business administration
○ Civil engineering

- Lebanese transportation engineers and planners

The survey was conducted from the beginning of July to the end of September. The distribution of responses, including the

Table B.1
Survey data: distribution of responses; the number of people contacted, those who accessed the survey, those who provided useful information and those who completed the full survey are reported.

	Group		
	Public	Private	General
Approx. Nb. contacted	120	150	100's
Nb. who accessed the survey	59	54	63
Nb. who provided useful data but did not fully complete taking the survey	48	45	38
Nb. who completed taking the survey	40	36	34
Total number of useful answers	**48**	**45**	**38**
Final total number of useful answers		131	

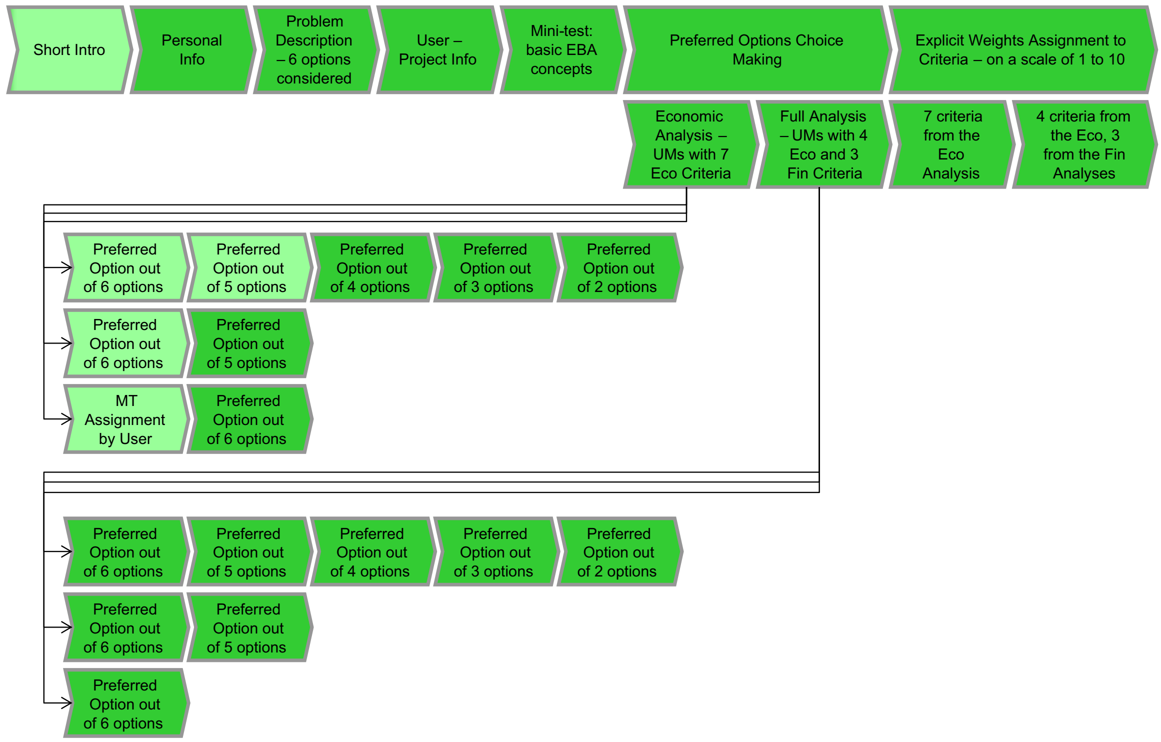

Fig. B.1. Web-survey steps; depicts the different sections of the survey and the steps that the respondent goes through in the process for the example of the Public Sector Site. The survey: interview tool and process.

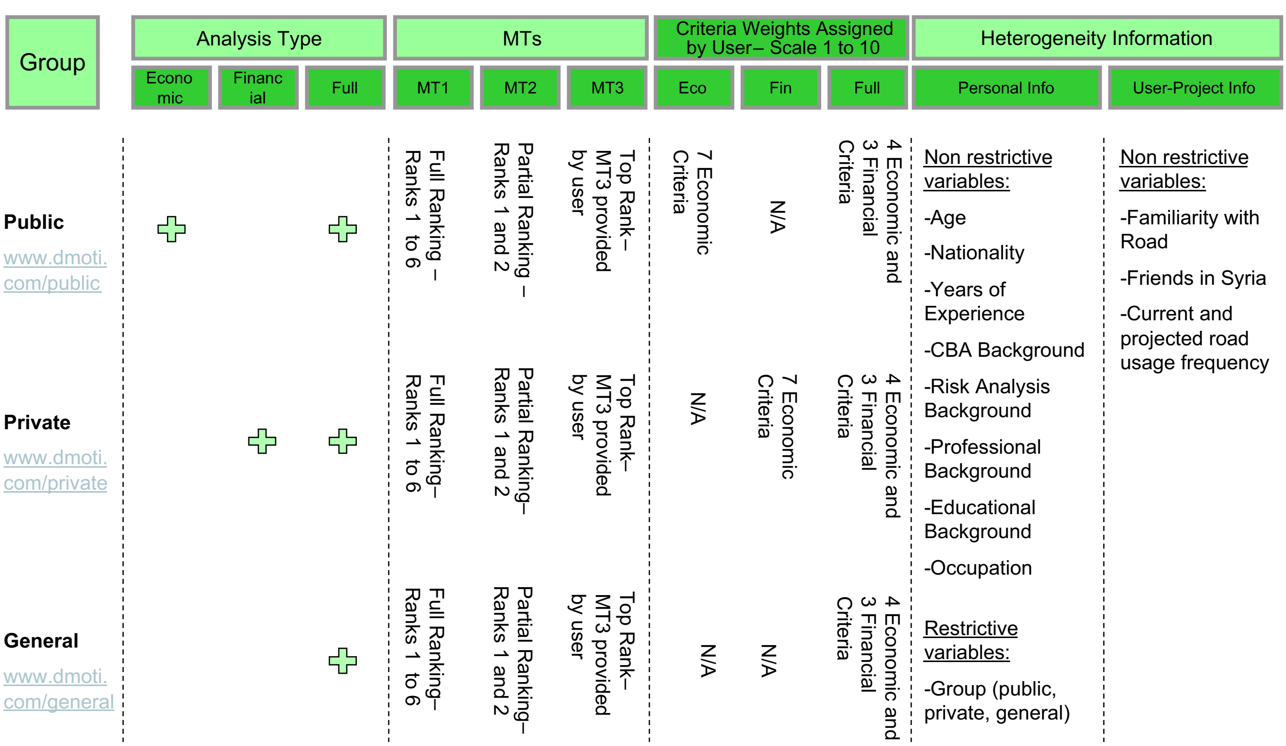

Fig. B.2. Survey design: architecture of data input; includes the analysis types, MTs, criteria weights' assignment, personal information and user/project information collected for each version of the site, the one for the Public Sector, the one for the Private Sector and the one for the General Public. Data collection and description of data. The architecture of the data input from the web-survey looks as shown in the figure.

number of people contacted, those who started but did not finish completing the survey, those who finished and those who provided enough useful information came out as presented in Table B.1 across groups:

Further details regarding survey tools and processes as well as the architecture of data collection and processing are presented in Figures B.1 and B.2.

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Glossary

IRR:: Internal Rate of Return;
NPV:: Net Present Value;
E[NPV]:: Expected Value of NPV;
E[ENPV]:: Expected Value of Economic NPV;
SD:: Standard Deviation;
ID:: Index of Dispersion;
CVaR:: Conditional Value-at-Risk;
VaR:: Value-at-Risk;
NPV-at-Risk:: equivalent to the VaR for the NPV;
EBA:: Elimination by Aspects;
TEBA:: Transportation EBA – a new evaluation and decision making framework proposed by the authors in this paper;
PWC:: Pairwise Comparison method – a method for estimating the parameters of an EBA model using pairwise choice information;
ROW:: Right-of-Way;
HSR:: High Speed Rail;
TT:: Travel Time;
VOC:: Vehicle Operating Cost;
Cr.: Criteria.