Integrating Sustainable Transportation in Decision-Making Processes: A Comparison Between Cost-Benefit Analysis and Multi-Criteria Decision Aiding

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Introduction

The recent shift in transportation planning from a car-centred approach towards a sustainable approach has greatly impacted transportation projects and planning. Transportation is no longer considered as an isolated discipline, but rather as a domain that must take into account interactions with other fields, such as environment, urban planning, public health. Throughout the years, many definitions of sustainable transportation have been proposed. However, these various definitions have led to ambiguity and to a lack of appropriate measurement tools and project assessment methods. As a result, a gap in decision-making processes was created between the visions and objectives for sustainable transportation and the day-to-day practices, often resulting in unsustainable projects (Marsden, Kimble, Nellthorp, & Kelly, 2010), a situation that was conceptually described by Banister (2008) as a *schizophrenic path*. To overcome this hurdle, some authors have suggested that transportation project evaluations and decision-making processes should be adapted to integrate multidimensional aspects, both qualitative and quantitative, and to include stakeholders from different fields of knowledge (Bueno, Vassallo, & Cheung, 2015).

Although the main methodology currently used in transportation project evaluation is cost-benefit analysis (CBA), multicriteria decision aiding (MCDA) is quite frequently used in some countries (Hayashi & Morisugi, 2000). However, no consensus has so far emerged in the transportation field regarding which method to use to integrate sustainability principles. Despite the common use of CBA, its application in transportation was not initially developed to take into account sustainability objectives; more and more authors in the transportation field are suggesting that MCDA may better integrate sustainability principles (Banister, 2008; Gudmundsson, Hall, Marsden, & Zietsman, 2016). To this effect, a few authors have compared CBA and MCDA from different perspectives on transportation: Bueno et al. (2015) compared the two approaches for infrastructure project evaluation, Browne & Ryan (2011) for transportation policies, and Beria, Maltese & Mariotti (2012) for transportation projects on a neighborhood scale. However, none of the published papers in transportation describe or analyze the different philosophies underlying CBA and MCDA; although that may help understand why some people are more comfortable working with CBA while others prefer MCDA.

The aim of this paper is to give an overview of the paradigms underlying CBA and MCDA and to compare the two methodologies through the prism of sustainable transportation. We first describe the different types of rationality in decision-aiding, followed by a brief presentation of the decision-aiding methodologies. Subsequently, based on a literature review, we summarize their strengths and weaknesses as identified by the various authors and conclude with a short discussion regarding some issues specific to transportation.

Rationality and Decision-Aiding Approaches

Many methodologies were developed throughout the years to assess transportation projects with the aim of being rational and neutral in choosing the "best" project. Nonetheless, there are various types of rationality,

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such as for example, the concepts of substantive rationality and procedural rationality introduced by Simon (1976). Substantive rationality is geared towards achieving a specific goal and is based on the assumption that actors have a clear pre-existing objective and that they act to maximize their utility or profit. On the other hand, procedural rationality, with origins in the behavioral and psychology fields, suggests that rationality rather depends on the process leading up to the decision. It is based on the assumptions that in complex situations, actors are only aware of a small part of the reality and that information is incomplete; they should therefore construct or be aided in constructing an appropriate reality within the decision processes (Simon, 1986). Following the work of Simon, Tsoukiàs (2008) later proposed four different approaches to decision-aiding: (1) a normative approach where rationality is established from norms and ideal economic behaviors; (2) a descriptive approach where rationality is derived from observing decision makers in order to build an empirical behavior model; (3) a prescriptive approach where rationality is discovered through preference modelling and decision aid; and (4) a constructive approach where rationality is a learning process to help build a new and common rationality for stakeholders.

Project Assessment Methodologies in Transportation

Cost-benefit analysis (CBA) is a methodology rooted in the economic field. It involves monetizing costs and benefits of each alternative according to selected forecast years and a discount rate. However, not all costs and benefits have direct market values. Therefore, in order to take into account aspects without market values, also called wider economic benefits, the valuation is usually done directly with stated preference methods such as willingness-to-pay (WTP) and willingness to accept (WTA) or indirectly with revealed preference methods like hedonic pricing (Nash, 1997). CBA then aims at finding, for a given problem, the solution that will achieve the greatest overall societal welfare. However, situations with only benefits and no downside effects for everyone rarely exist in reality. To resolve this difficulty, CBA was established on utilitarianism principles and according to the Hicks-Kaldor compensation test (van Wee, 2011): an act is considered right, only if the societal welfare improvement is "higher" for those who gain than the negative impacts on those who lose (De Brucker, Macharis, & Verbeke, 2013; Saarikoski et al., 2016). Consequently, alternatives are compared according to the benefit-to-cost ratio or the actual net value difference in order to determine the alternative with the highest societal welfare (Mackie & Nellthorp, 2001).The assumptions made by CBA imply a substantive rationality and a normative approach.

Multi-criteria decision aiding (MCDA) was developed in the field of operational research. It consists of a family of methods that seek to explicitly take into account multiple criteria (Belton & Stewart, 2002). Following discussions and debates with the stakeholders, a MCDA process can help create a consensus around a common value framework that involves multidimensional aspects and takes into account criteria from different fields (Munda, 2005; Riera Pérez & Rey, 2013; Roy, 2016). A MCDA process is usually split in two main phases: a problem structuring phase and a model building phase. Problem structuring aims at identifying the values, the concerns and the issues of stakeholders and constructing a set of criteria. Model building seeks to define the inter and intra criteria information that will serve to assess the alternatives.

There are three main schools of thought in MCDA: Single-synthetizing criterion methods that build utility or value functions (cardinal data), outranking-based methods that build binary preference relations (ordinal data), and rule-based methods that infer decision rules to model the decision maker's preferences. Single-synthesizing criterion methods including MAUT, AHP and MACBETH are totally compensatory methods and yield total pre-orders where all the alternatives are ranked from best to worst with a possibility of ex-aequo (Dyer, 2016; Saaty, 2016; Bana e Costa, De Corte, & Vansnick, 2016). Outranking-based methods including the ELECTRE family do not necessarily lead to transitive rankings and total comparability between the alternatives (Figueira, Mousseau, & Roy, 2016). Rule-based preference methods build *if …then* types of rules to guide in the selection of alternatives (Greco, Matarazzo, & Słowiński, 2016). The philosophy behind MCDA implies a *procedural rationality* and a *prescriptive* or a *constructive* approach. Although utility based methods are traditionally considered normative, according to Tsoukiàs (2008), it is

not the method that defines the decision approach, but rather how rationality is conceived and how the decision process is conducted.

Another methodology called multiple account evaluation (MAE), or multiple account cost-benefit analysis, is popular for project assessment in Canada. MAE's particularity is to consider the different interests and objectives of stakeholders by introducing the concept of account. Each account represents a different point of view. The performances of alternatives on each account are presented in a disaggregated form to decision-makers (Crown Corporations Secretariat, 1993; Shaffer, 2010). Depending on the case study, MAE is sometimes applied in a more substantive rationality and other times in a more procedural rationality. The creation of accounts for each point of view is similar to multi-actor multicriteria analysis (MAMCA) where a model is constructed for each actor (Macharis, Turcksin, & Lebeau, 2012).

Literature Review Methodology

In order to identify the papers related to CBA and MCDA in the transportation field, we searched two multidisciplinary databases (Web of Science and ABI-INFORMS) and two transportation-related databases (Transport research international documentation (TRID) and OVID transport). The search was limited to papers published in peer-reviewed journals and conference proceedings. The period of search was not limited. The search was performed using the following keywords: multi-criteria analysis (or multicriteria decision analysis, or multi-criteria decision-making, or multi-attribute analysis, or multicriteria decision aiding, or mca, or mcda), and cost-benefit analysis (or benefit-cost analysis, or cba) and transport (which is included in transportation). Furthermore, the keyword transport was not used in the TRID and OVID transport databases since they are transportation-specific databases. Based on this search, we obtained 128 publications, 76 of which were discarded as irrelevant. Based on the reference section of the retained papers, cross-referenced papers were also included in our literature review process (n=10). Furthermore, a conference paper from the same authors and on the same subject later published in a journal was considered as a duplicate; only the journal paper was included. Finally, the papers were classified into four main categories: CBA and MCDA comparison (n=15); CBA and MCDA combination (n=26); MCDA used and CBA mentioned (n=11); and CBA used and MCDA mentioned (n=15). A small number of papers were classified in two categories (n=3). In this paper, only the 41 papers pertaining to the comparison and combination of CBA and MCDA are discussed.

CBA and MCDA Comparison

Papers comparing CBA and MCDA were split in two categories: (1) papers describing the advantages and disadvantages of CBA and MCDA and (2) papers highlighting the differences in the results obtained when both methodologies were applied to the same project. Tables 1 and 2 present a summary of the strengths and weaknesses identified in the literature. These vary depending on the author's rationality and the decision aiding approach. For a same methodology, what was considered a weakness from a substantive rationality and a normative approach could be viewed as a strength from a procedural rationality and a constructive approach, or vice-versa. For example, some authors praise CBA because it easily communicates results in an understandable language through monetary terms while other authors argue that CBA hides information behind monetary values that decision-makers may not understand.

The two papers that compared results obtained when the two methodologies were applied for the same project reported differences in the outputs (Leviankangas et al., 2002; Tudela, et al., 2006). The preferred projects following a CBA were not the same as those following a MCDA. Tudela et al. (2006) explained these differences by the lack of consideration of non-economic aspects in CBA. The case study showed that the provision of information through a MCDA process allowed people to be more aware of factors such as noise and visual impacts for example; which translated into a weight shift from the CBA parameter to the MCDA parameters for the noise and visual impacts. As for Leviakangas et al. (2002), they justified the differences by observing that CBA was not flexible enough to assess new kinds of transportation such as intelligent transportation systems, a limitation that was not observed through their application of MCDA.

Table 1 Comparison of advantages and disadvantages of CBA

CBA advantages	CBA Disadvantages
+ relies on well-known assumptions based on an established theory (Dimitriou et al., 2016)	– assumptions overestimate the advantages of cars compared to other transportation modes by mainly taking travelling time saving into account (Browne & Ryan, 2011)
+ compares straightforward costs and benefits in a rigorous, transparent and formal way (Babashamsi, Yusoff, Ceylan, Nor, & Jenatabadi, 2016)	– is not transparent because the economic assumptions used are rarely revealed (Annema et al., 2015)
+ assesses economic efficiency (Browne & Ryan, 2011)	– underestimates or ignores non-monetary aspects or intangible aspects that are not traditionally included in CBA (Quinet & Meunier, 2012) – limited concern toward equity and distribution impacts (Babashamsi et al., 2016)
+ easily communicates results in an understandable language to decision makers through monetary terms (Hüging, Glensor, & Lah, 2014)	– oversimplifies reality by transforming everything into monetary values according to linear functions – hides information behind monetary values that decision-makers may not understand (Galves, 2005)
+ captures the consumer values of "everyone" using the willingness-to-pay concept (Dimitriou et al., 2016)	– tries to monetize intangible aspects and moral values which is ethically dubious(Hüging et al., 2014) – excludes stakeholders by its non-participative nature – conceives that consumers only have individual values and no collective values (Dimitriou et al., 2016)
	– requires extensive amounts of data to assess alternatives which can be problematic for small organizations (Rudolph et al., 2015)

Table 2 Comparison of advantages and disadvantages of MCDA

MCDA Advantages	MCDA Disadvantages
+ includes stakeholders and their various perspectives in the decision-making process which contribute to developing consensus (Browne & Ryan, 2011)	– aggregation forces the consensus within a group or stakeholders with different opinions – participatory processes with many stakeholders are resource and time consuming (Hüging et al., 2014)
+ resolve conflict and legitimize the decision (Dimitriou et al., 2016)	– the weight definition and how it is applied may be biased, non-transparent and subjective (Quinet & Meunier, 2012)
+ integrates every aspect of project assessment including monetary aspects, quantitative aspects and intangible aspects (Hüging et al., 2014) + multidisciplinary and holistic approach (Galves, 2005)	– forces the aggregation of incomparable aspects through weighting (Browne & Ryan, 2011)
+ composed of several methods which allows it to be adapted to different types of problem (Babashamsi et al., 2016)	– complexity of the mathematics used in assessment creates a black box effect about the methodology (Griskeviciute-Geciene, 2010)
+ structures an ill-defined and complex problem into a set of structured and explicit choices which give a broader picture of the situation and stakeholder preferences (Galves, 2005)	
+ informs decision-makers of the degree of accomplishment for each objective (Bristow & Nellthorp, 2000)	

Combination of CBA and MCDA

Several reasons may justify the use of a combination of methodologies. In most cases, it is a way to improve traditional CBA by developing new assessment frameworks. More specifically, the combination allows one to: overcome the hurdles related to integrating non-monetizable, non-quantitative or intangible aspects (Ambrasaite, Barfod, & Salling, 2011; Gühnemann, Laird, & Pearman, 2012); provide more information about the alternatives to decision makers (Barfod, Salling, & Leleur, 2011); better cope with complex problems by giving a more holistic and multidisciplinary perspective (Salling & Pryn, 2015); take into account equity concerns and better redistribute impacts (Thomopoulos & Grant-Muller, 2013); and include the various stakeholders in the decision process (Macharis, Milan, & Verlinde, 2014). The only identified criticism is that the combination of two already complex methodologies for decision-makers may further complicate project appraisal and create a bigger black box effect (Annema et al., 2015). We identified four different CBA and MCDA combination types: (1) the MCDA results are monetized and included within the CBA, (2) the CBA results are included as one or several economic criteria within the MCDA, (3) the CBA and the MCDA results are presented in a disaggregated manner in parallel, and (4) CBA and MCDA are two different steps in the decision-making process.

Although there were several reasons for choosing a given combination type, the authors were not always explicit about their reasons. For some authors, CBA is preferred as the overarching framework because the use of an investment return rate is more familiar to decision-makers than the use of an aggregated MCDA score (Barfod et al., 2011), and because the inclusion of MCDA in the process allows for wider economic benefits to be considered (Salling, Leleur, & Jensen, 2007). Interestingly, the COSIMA method (based on CBA as an overarching framework and subject of several papers), was recently abandoned by its creators because they judged it too difficult to apply in practice. They suggested that including CBA results within a MCDA framework was more appropriate because it was difficult to elicit the shadow prices and the economical trade-offs of MCDA components in a CBA overarching framework (Barfod & Salling, 2015; Salling & Pryn, 2015). Another reason is that costs should be interpreted just like a criterion among the others in a MCDA (Tsamboulas & Mikroudis, 2000). In other cases, CBA and MCDA results are presented in a disaggregated manner because it allows decision-makers to better see the trade-offs and the distribution of impacts. This approach is favored by some authors for whom the complementary nature of CBA and MCDA implies that they should not be aggregated, and because the obtained results represent two distinct sets of values (i.e. CBA represents consumer values whereas MCDA represents decision-maker values; Bobinger, Flowerdew, Hammond, Himanen, & Keller, 1991; Panou & Sofianos, 2002; Thomopoulos & Grant-Muller, 2013). Finally, Prosser, Fensham and Schmahmann (2015) prefer to combine the two methodologies as a series of appraisals because MCDA allows one to appraise alternatives at the strategic level where CBA allows one to appraise a subset of alternatives at the project level; thereby taking advantage of the respective strengths of each methodology. Since both methodologies or their combination are subject to the same sources of errors such as data or transportation model uncertainties, their application is often supported by a feasibility risk assessment, a scenario analysis or a sensitivity analysis to better handle uncertainties. Such analyses examine the impact of varying weights or monetary units (Gühnemann et al., 2012; Tsamboulas & Mikroudis, 2000) or model inputs such as transportation demand forecast and construction cost estimation (Barfod & Salling, 2015).

Discussion and Conclusion

Many papers reviewed in our study mention the presence of a cycle within national transportation project appraisal guidelines between more economic approaches and more multicriteria and participative approaches. This is for example the case in the Netherlands and in France (Jong & Geerlings, 2003; Quinet & Meunier, 2012). Nonetheless, regardless of the methodology used, project appraisal is often seen by decision-makers and by professionals as a hurdle to overcome rather than a process to improve decision-making: appraisals are a way to obtain funding to conduct a project (Rudolph et al., 2015), appraisal results are publicly mentioned if politically popular, but ignored in other cases (Annema et al., 2015), and there is a strategic behavior to underestimate costs and overestimate benefits from actors who stand to gain from a

project (Flyvbjerg, Holm, & Buhl, 2002). Furthermore, the literature review showed that a key element for the acceptance of a transportation project is usually its potential to reduce traffic and travel time. These represent 50% to 90% of the benefits expected from new infrastructures (Mackie & Nellthorp, 2001). However, the overreliance on travel time gain may lead to discarding transportation projects that have almost no gain in time, although having other benefits harder to measure. Moreover, the inclusion of sustainability in transportation appraisal raises the question of whether new metrics should be developed and included.

In summary, the strengths of CBA and the weaknesses of MCDA identified in the literature can be linked to a substantive rationality whereas the strengths of MCDA and the weaknesses of CBA can be associated with a procedural rationality. The combination of both methodologies shows that it is possible to improve existing decision frameworks, but that this combination has mostly served to solve problems inherent to CBA. Although none of the methodologies is exempt from weaknesses, the use of one or the other will always improve decision-making relative to unaided decision-making. However, in complex and uncertain environments such as sustainable transportation, the use of MCDA or the combination of CBA and MCDA may give a better representation of reality than CBA alone. Consequently, further research should be conducted in transportation on how to develop new decision frameworks based on MCDA or on a combination of CBA and MCDA to better include sustainability principles. The case study of the Central Porto high-speed railway station is a good example of new framework that could be developed (Mateus, Ferreira, & Carreira, 2008).

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