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A review of cost-benefit analysis and multicriteria decision analysis from the perspective of sustainable transport in project evaluation

Francis Marleau Donais[1*], Irène Abi-Zeid[2], E. Owen D. Waygood[3] and Roxane Lavoie[1]

[1] Graduate School of Land Management and Regional Planning, Université Laval, Québec, Canada
[2] Department of Operations and Decision Systems, Université Laval, Québec, Canada
[3] Department of Civil, Geological and Mining Engineering, Polytechnique Montréal, Montréal, Canada

***Corresponding author information :**
Francis Marleau Donais
Pavillon Félix-Antoine Savard, office FAS-1616
2325, allée des Bibliothèques, Université Laval
Québec (Québec) G1V 0A6 Canada
Email: francis.marleau-donais.1@ulaval.ca
Phone : 1-418-656-2131 #4463
Fax : 1-418-656-2018
ORCID : 0000-0002-1970-7079

Abstract:
Transport decision processes have traditionally applied cost-benefit analysis (CBA) with benefits mainly relating to time savings, and costs relating to infrastructure and maintenance costs. However, a shift toward more sustainable practices was initiated over the last decades to remedy the many negative impacts of automobility. As a result, decision processes related to transport projects have become more complex due to the multidimensional aspects and to the variety of stakeholders involved, often with conflicting points of view. To support rigorous decision making, multicriteria decision analysis (MCDA) is, in addition to CBA, often used by governments and cities. However, there is still no consensus in the transport field regarding a preferred method that can integrate sustainability principles. This paper presents a descriptive literature review related to MCDA and CBA in the field of transport. Among the 66 considered papers, we identified the perceived strengths and weaknesses of CBA and MCDA, the different ways to combine them and the ability of each method to support sustainable transport decision processes. We further analysed the results based on four types of rationality (objectivist, conformist, adjustive and reflexive). Our results show that both methods can help improve the decision processes and that, depending on the rationality adopted, the perceived strengths and weaknesses of MCDA and CBA can vary. Nonetheless, we observe that by adopting a more global and holistic perspective and by facilitating the inclusion of a participative process, MCDA, or a combination of both methods, emerge as the more promising appraisal methods for sustainable transport.

Keywords: Sustainable transport, multicriteria decision analysis, cost-benefit analysis, rationality, decision aiding

1 Introduction

The increasing awareness of social inequities and environmental degradation related to anthropogenic activities has led researchers and practitioners since the end of the 20th century to define the concept of sustainable development and to explore new solutions. As a result, many related environmental sectors such as energy or agriculture production have adjusted their practices in order to integrate sustainability (Elzen et al. 2004). Transport is no exception; in response to the numerous documented negative impacts of the transport networks specifically designed for automobility (noise, air pollution, public health degradation, urban sprawl, traffic, social inequity, etc; Nieuwenhuijsen et al. 2019), the concept of sustainable transport[1] has emerged and several definitions were proposed (Gudmundsson et al. 2016). The definition adopted in this paper is that of Holden et al. (2013) where sustainable transport is defined as a system of transport that safeguards long-term ecological sustainability, satisfies basic human needs and promotes intragenerational and intergenerational equity.

Nevertheless, a path dependency toward unsustainable behaviours and practices is still found in transport (Curtis and Low 2012; Driscoll 2014), a situation also encountered in other fields such as agricultural technology (Vanloqueren and Baret 2009), energy production (Lafferty and Ruud 2008) or urban water management (Brown and Farrelly 2007). A path dependency is defined as a sequence of steps during a problem solving or modelling process that will lead inevitably to similar outcomes or solutions (Geels et al. 2012). Despite the inclusion of sustainability objectives in project assessments, there is often a gap between potential decision processes, meant to be coherent with sustainable transport objectives, and the existing decision processes, that still allow for unsustainable transport infrastructures and policies (Marsden et al. 2010). This is illustrated by Finnveden and Åkerman (2014) using two case studies in Sweden where, by not including long-term climate goals and project impacts on future transport systems such as the generation of new traffic, infrastructure assessment practices have led to unsustainable solutions. This was also observed by Banister (2008) who coined the term *schizophrenic path* to describe this situation: "when it is clear that action is needed, but no effective action is taken to remedy the situation". Therefore, a better understanding of current project assessment methods and their associated weaknesses and strengths is needed to help improve the integration of sustainability principles into current transport project assessment practices.

To support rigorous strategic decision-making, several methods may be used for the assessment of transport projects. Two such methods are generally used by governments and cities: cost-benefit analysis (CBA)[2], the most widespread and frequently applied project evaluation method in transport, and multicriteria decision analysis (MCDA). Other methods that quantify economic impacts, such as techno-economic analysis (TEA), cost-effectiveness analysis (CEA) or activity-based costing (ABC), are sometimes used; but they are not as widespread as CBA and are therefore outside the scope of this paper. CBA may be more commonly used; however, MCDA is quite often used in countries such as Austria, Belgium and Germany (Hayashi and Morisugi 2000; Bristow and Nellthorp 2000; Odgaard et al. 2006; Mackie et al. 2014). To this day, no consensus has yet

[1] The term sustainable mobility is also used by some authors. The difference between the two is that mobility refers to the potential of a person to move from an origin to a destination whereas transport refers to the travel of a person from an origin to a destination. In this paper, the term sustainable transport will be used.

[2] CBA is also known as Benefit-Cost Analysis (BCA), which may be a better term as the name is more coherent with the method. However, the term CBA will be used in this paper since the majority of the literature uses this term.

emerged in the transport field regarding the preferred method for integrating sustainability principles.

Since the application of CBA in transport was not initially developed to take into account sustainability objectives, some authors have suggested that MCDA may better integrate sustainability principles (Banister 2008; Gudmundsson et al. 2016). In parallel, other authors have advocated combining both methods to address different aspects of the same project (Haezendonck 2007; Beria et al. 2012; Mouter et al. 2013). This has led to a flourishing development of appraisal frameworks in transport, albeit with no agreement on whether and how CBA and MCDA should be combined, or if one method is actually better than the other in terms of taking into account sustainability objectives.

A few papers, comparing CBA and MCDA from the perspective of their respective fields, can be found in the literature on the environment (Joubert et al. 1997; Saarikoski et al. 2016), on environmental risk management (Brouwer and van Ek 2004; Gamper et al. 2006), on energy (Medjoudj et al. 2013), on sustainable development (De Brucker et al. 2013) and on water management (Lai et al. 2008). However, such literature reviews in the field of transport are rare and are narrative reviews (Browne and Ryan 2011; Beria et al. 2012; Bueno et al. 2015). Furthermore, they do not involve a systematic or a comprehensive search of all the literature and therefore, lack methodological information and cannot be replicated. In addition, none of the published papers in the transport field addressing CBA and MCDA describe or analyse the different philosophical backgrounds, or rationalities, underlying the two, a necessary step to understand why some individuals choose CBA while others prefer MCDA.

The aim of this review paper is to present a descriptive literature review related to MCDA and CBA based on a structured coverage and an explicit selection strategy of journal and proceeding papers. Our main goal is to compare the use of the two methods, in the context of sustainable transport, from the perspective of the different rationality conceptualisations defined by Meinard and Tsoukiàs (2018): objectivist, conformist, adjustive and reflexive (discussed in further details in section 2). A descriptive review (Paré et al. 2015) was therefore deemed relevant since our goal is not limited to identifying what is written on the different methods, but rather to apply a search strategy that cover a representative sample of the literature and to perform a content analysis. Moreover, to enhance the quality of this literature review, we followed the relevant guidelines given by Templier and Paré's (2018) for systematicity and transparency of literature review evaluations.

More specifically, this paper aims to answer the following research questions:

- What are the perceived strengths and weaknesses of CBA and MCDA, and how are these perceptions related to different rationalities underlying decision-aiding processes?
- What are the different ways of combining CBA and MCDA and what motivates their combination in those differing ways?
- Do either (or both) CBA and MCDA have the capability to include sustainability in transport in project assessments?

This paper is structured as follows: Section 2 describes the four decision-aiding approaches and contains an overview of CBA, MCDA and project assessment frameworks used in transport. Section 3 presents our literature review methodology. Section 4 presents a general analysis of the reviewed papers and summarizes the perceived strengths and weaknesses of CBA and MCDA with an emphasis on sustainable transport. Section 5 describes how CBA and MCDA are combined in

the literature, the rationale behind the various combination frameworks and the reasons for preferring one framework over another. Section 6 discusses the comparison results from the perspective of different decision-aiding approaches and analyses CBA's and MCDA's capability to better integrate sustainability in project assessments. Finally, Section 7 summarises the paper and explores future avenues for research related to project assessment in transport.

2 Project assessment in transport

Addressing transport problems implies dealing with complex situations and unexpected consequences. Solutions come in many forms, including policies (carbon taxation, land-use policies, technological regulation) or infrastructure development (highways, highspeed trains, tramway lines); also referred to as soft and hard interventions respectively. Decision-makers need to appreciate the compromises between the investments required, the potential to achieve the desired outcomes, and the different impacts on society. Therefore, the main aim of transport project assessment is to produce and communicate relevant information to enable the decision-makers to acquire full knowledge of transport problems and issues (Meyer and Miller 2001; Haezendonck 2007; Notteboom and Winkelmans 2007).

Nonetheless, what is considered a "good" decision may vary depending on the type of rationality pursued. Putting the question of sustainability aside for the moment, a better understanding of what is a "good" decision can be discussed from a rationality perspective. Genard and Pirlot (2002) explored the concept of decision-aid model validity from a philosophical perspective according to the four pretensions to validity that form a whole called rationality by Habermas: truth, normative justness, sincerity and intelligibility. Then, following the work of Simon (1976), Tsoukiàs (2008) expanded on the four approaches to decision-aiding (normative, descriptive, prescriptive and constructive). However, in order to take into account the social dimension of rationality in decision processes, Meinard and Tsoukiàs (2018) defined four new decision-aiding approaches based on the concept of communication action from Habermas. In this literature review, we adopt their definitions as follows:

a) an objectivist approach where rationality is strategically shaped and accepts that there are unquestionable formulations of problems and solutions (strategic conception of rationality and similar to a normative approach);
b) a conformist approach where rationality is derived from observing stakeholders in order to build an empirical behaviour model (norm-regulated conception of rationality and similar to a descriptive approach);
c) an adjustive approach where rationality is unique to a particular context according to stakeholders' needs, preferences and values (dramaturgic conception of rationality and similar to a prescriptive approach);
d) a reflexive approach where rationality is a learning process to build a new rationality with no authoritative conception, no behavioural expectations and no inner preferences (communicative conception of rationality and similar to a constructive approach).

The above decision-aiding approaches structured the theoretical framework that was used to analyse the papers in this review. The following sub-sections describe CBA (section 2.1) and MCDA (section 2.2), two project assessment methods commonly used to aid decision-makers and how they are included in assessment frameworks (i.e. how a method or several methods are used in practice to assess projects) depending on the country (section 2.3).

2.1 Cost-benefit analysis

Cost-benefit analysis (CBA) is a method rooted in the field of economics. CBA aims at finding, for a given problem, the solution that will achieve the greatest overall societal welfare. It involves monetising the socio-economic costs (negative impacts) and benefits (positive impacts) of each alternative over the life of a project. The range of impacts (be they positive or negative) are typically limited due to technical constraints. For example in situations where it is not possible to assign a market value to a given impact, the valuation is estimated directly using stated preference methods such as willingness-to-pay (WTP) and willingness to accept (WTA) or indirectly using revealed preference methods like hedonic pricing (Nash 1997). WTP represents the monetary amount that an individual would pay to obtain a good (e.g. a person could be asked in a stated preference survey: *how much would they pay per month to reduce crowding in metro during peak hours?*). WTA represents the minimum monetary amount required to compensate the loss of a good (Brown and Gregory 1999). For example, a person may be asked *how much is required to compensate for the increase in noise caused by a new motorway near their residence?* As for hedonic pricing, it examines the relationship between the sale price of a good, its physical and environmental characteristics in order to quantify the value of a specific characteristic. For example, to measure the price of accessibility, the increase in price, over a given time period, of houses near a new train station compared to the increase in price, over the same time period, of similar houses that are not close to a train station, can be examined to determine the hedonic price effect (Dubé et al. 2013). A CBA that includes these non-market values is sometimes called social cost-benefit analysis as opposed to a traditional CBA (Haezendonck 2007).

Furthermore, considering that costs and benefits may arise at different points over the lifetime of a project, CBA requires the conversion of future monetary values to net present values through discounting, based on a reference period and a discounting rate. These parameters vary depending on the country's appraisal guidelines. For example, in the field of transport planning, in the United States, the discount rate is 7% and the evaluation period depends on the project's lifetime (25-30 years), whereas, in the United Kingdom, the discount rate is between 2.5% and 3.5 % and the evaluation period is by default 60 years (Gwee et al. 2011; Mackie et al. 2014). The reference period aims at determining the period over which the impacts will be considered. A longer reference period will include more long-term effects in the evaluation. As for the discounting, it is based on the assumption that benefits or costs that occur in the short term are more relevant than the ones occurring in the long term. The higher the discount rates, the lower the value of future costs and benefits in a CBA. Thus, future impacts such as climate change would be more heavily discounted (given lower consideration) in the American system as compared to the British one.

A project that achieves only gains/benefits without any losses/costs should, of course, be implemented. However, situations with only benefits and no downside effects rarely exist in real life. To resolve this conundrum, CBA was established on utilitarian 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 et al. 2013; Saarikoski et al. 2016). Consequently, alternatives are compared according to the benefit-to-cost ratio (BCR) or the net present value (NPV) difference in order to determine the alternative with the highest societal welfare (Mackie and Nellthorp 2001). A BCR value that is larger than 1 or a positive NPV are signs that the project is economically efficient. Transforming effects into monetary values and aggregating them through a BCR or NPV allows for a complete compensation between the different considered effects (Ackerman and Heinzerling 2004).

2.2 Multicriteria decision analysis

Multicriteria decision analysis (MCDA) was developed in the field of operational research. It consists of a family of methods that aim at explicitly taking into account multiple criteria (Belton and Stewart 2002). MCDA is also called multi-criteria decision-making or multi-criteria decision aiding. Following discussions and debates with the stakeholders, a MCDA process can help create a consensus around a common value structure that involves multidimensional aspects and takes into account criteria from different fields (Munda 2005; Roy 2016). MCDA can help solve three types of problems: choice problematic (selection of one or of a small set of alternatives among several), sorting problematic (classification of alternatives according to predefined categories) and ranking problematic (partial or complete ordering of alternatives). A MCDA process consists usually of two main phases: (1) a problem structuring phase and (2) a model building and alternatives assessment phase. Problem structuring aims at identifying the values, the concerns and the issues of stakeholders and constructing a set of criteria and alternatives. Model building seeks to define the parameters that will serve to assess the alternatives. Since it is rooted in stakeholders' preferences and objectives, MCDA is often referred to as objective-driven as opposed to market-driven or efficiency-driven for CBA. Two of three main schools of thought in MCDA have been used in transport assessment projects: single-synthesising criterion methods that build utility or value functions (cardinal data) and outranking-based methods that build binary preference relations (ordinal data; Greco et al. 2016a).

2.2.1 Single-synthesising criterion methods

Single-synthesising criterion methods are compensatory methods and yield total pre-orders where all the alternatives are ranked with a score from best to worst with a possibility of *ex-aequo* (alternatives with equal scores). They are based on two basic preference relations (strict preference and indifference). They involve building partial value functions for every criterion and aggregating them through different forms of weighting to build a global value function. The weighting in single-synthesising criterion methods does not represent the importance of criteria, but rather the relative importance of criteria as a function of the constructed local value functions, with AHP (Analytic Hierarchy Process) being an exception (Belton and Stewart 2002). Throughout the years, various methods have been developed including MAVT (Multi-Attribute-Value-Theory; Dyer 2016), MACBETH (Measuring Attractiveness by a Category-Based Evaluation Technique; Bana e Costa et al. 2016) and AHP (Saaty 1977, 2016).

2.2.2 Outranking methods

Outranking methods are partial compensatory ordinal methods where the alternatives are ranked from best to worst (in a ranking problematic) with a possibility of *ex-aequo* and of incomparability (partial pre-orders). They are based on four basic preference relations (indifference, strict preference, weak preference and incomparability) used to define an outranking relation (an alternative A is at least as good as an alternative B). These methods involve determining outranking relations between the alternatives based on pairwise comparisons and on credibility indices of the assertion *A is at least as good as B*. Some methods use weights that represent the voting power of criteria. Various outranking methods have been developed throughout the years including the ELECTRE family and some versions of PROMETHEE (José Rui Figueira, Mousseau, & Roy, 2016; Brans & Smet, 2016).

2.3 Similarities between the methods

Despite being developed in two different fields, CBA and MCDA single-synthesising criterion methods share several similarities (Marshall et al. 2011). They both aim at improving the decision

process by rigorously comparing the advantages (benefits) and the disadvantages (costs) of each alternative. To compare the alternatives, they both involve a form of weighting and transform original units into uniform units for comparison. However, the underlying preference types are different: CBA use the sum of individual consumer preferences (i.e. monetary values and shadow prices) whereas MCDA use the involved stakeholders' preferences (i.e. utility functions, swing weights…). In fact, the results of a CBA and an MCDA will be the same in the very specific and limited conditions where: the criteria scores are the same, the shadow prices are equal to the MCDA weights, the weight on cost is unity and the MCDA aggregation method used is a weighted sum (Atkinson et al. 2018). Moreover, CBA and single-synthesising criterion methods both allow a complete compensation between the criteria (Browne and Ryan 2011). The possible undesirability of a total compensation effect is one of the factors that led to the development of MCDA outranking methods that are partial compensatory methods (Roy 1985).

2.4 An overview of some assessment frameworks in transport

Various transport project assessment frameworks have been designed, in different countries, based on CBA and MCDA. These frameworks involve mainly CBA with BCR and NPV, although some frameworks also include non-monetised and qualitative impacts. The way these non-monetised impacts are included in the analysis varies: some frameworks evaluate environmental impacts or conduct life-cycle analysis (also known as life-cycle assessment) separately, while others integrate CBA explicitly into a MCDA or a summary table (i.e. a table that presents the alternative's impacts according to several dimensions, unaggregated). Moreover, it is not typically the choice of an individual or a group to decide whether a CBA or a MCDA should be used, rather, it is a requirement from governmental administration such as a Department of Transport. In the majority of western countries, conducting a CBA or an economic assessment according to specific guidelines is a prerequisite to any transport project development (Odgaard et al. 2006; Hayashi and Morisugi 2000; Bristow and Nellthorp 2000; Mackie et al. 2014). The next paragraphs present some of these frameworks.

In Denmark, the *Overview of the Effects of Infrastructure* (OEI manual, previously known as OEEI) recommends monetising effects as much as possible. Subsequently, the non-monetised effects are presented in parallel with a qualitative description (Jong and Geerlings 2003; Mouter et al. 2015). In Germany, the *Federal Transport Infrastructure Plan* assesses projects according to four different modules: cost-benefit analysis, environmental and nature conservation, spatial planning, and urban development. However, it is not clear how these different modules interact (Federal Ministry of Transport and Digital Infrastructure 2016).

In the United States, projects that are funded by the federal government require a CBA. However, regional level projects that are planned by Metropolitan Planning Organizations often use a variant of MCDA (Hayashi and Morisugi 2000; Mackie et al. 2014). In Canada, the assessment frameworks differ depending on the province, but are usually based on a CBA or a MCDA. One framework used in the provinces of Alberta and British Columbia is *Multiple Account Evaluation* (MAE). The MAE's particularity is to consider the different interests and objectives of stakeholders by introducing the concept of an account. Each account represents a different point of view (financial performance, customer service, environment, economic development and social). The performances of alternatives within an account can be aggregated, but individual accounts' performances are presented in a disaggregated form to decision-makers (Crown Corporations Secretariat 1993; Shaffer 2010).

In Australia, the CBA Guidelines introduced the concept of *Adjusted CBA* as an optional appraisal technique, presented as a hybrid of CBA and MCDA. The guidelines suggest weighing the costs and benefits in order to better represent the government's objectives and are therefore more policy-driven (Australian Transport Assessment and Planning 2018). In Japan, a CBA is used as a filter to screen the projects and retain only those deemed worthy of further investigation. The remaining projects are then ranked using a *Benefit Incidence Table* acknowledging, for each stakeholder, whether the effects are positive or negative and whether it is possible to measure these effects (measurable in monetary terms, roughly measurable and difficult to measure). However, it is not clear how the tables are interpreted.

3 Methodology

The procedure used to review the literature consists of five steps: (1) formulating the problem, (2) searching the literature, (3) screening for inclusion, (4) extracting data and (5) analysing and synthesising data (Templier and Paré 2015). In order to identify the papers related to CBA and MCDA in the transport field, two multidisciplinary databases (Web of Science and ABI-INFORMS) and two transport-related databases (Transport research international documentation (TRID) and OVID-transport) were searched. The keywords used were variants of *multicriteria decision analysis* AND *cost-benefit analysis* AND *transport* (Fig. 1). The search was limited to papers published in peer-reviewed journals and conference proceedings. The covered language was English. The keyword *transport* or one of its variants were not used in the TRID and OVID-transport databases since they are transport-specific databases. Fig. 1 summarises the literature screening process in a flow diagram.

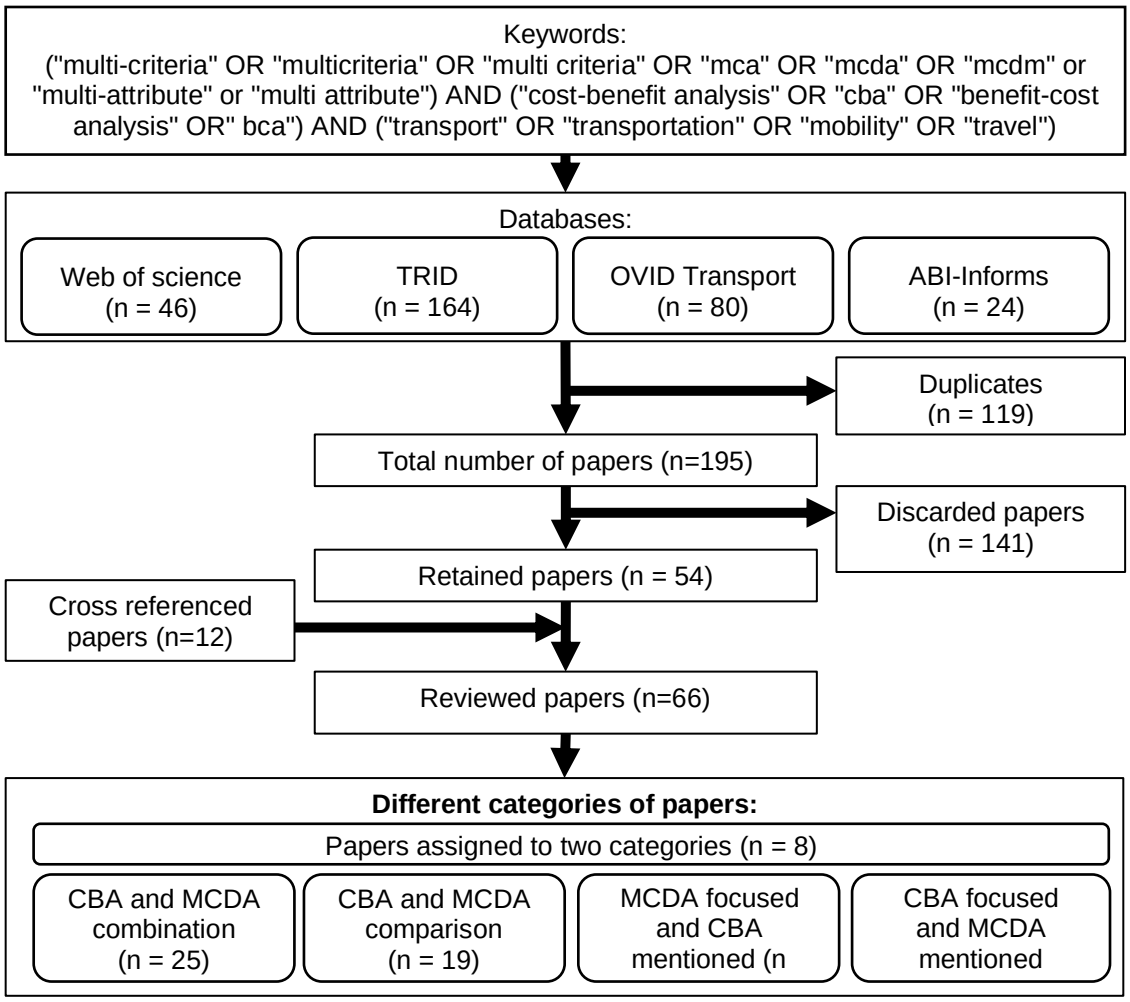

Fig. 1: Flow diagram of literature screening process

The period of the literature search was limited to publications from 2000 to 2018. This choice was made in order to reflect the current state of CBA and MCDA; the two methods and their practices have evolved significantly over the last two decades. The papers were filtered based on the title and the abstract, and only those relevant to the research questions were retained. Furthermore, only papers about ground-based transport for people or land freight transport were kept; papers about sea and air transport were discarded. This choice was made because they represent a different type of transport problem and usually involve different decision processes. Furthermore, a conference paper from the same authors and on the same subject later published in a journal was considered a duplicate; in these cases, only the journal papers were included in the review. To minimise publication bias and mitigate the search tools limitations, cross-referenced papers were also included in our literature review (n=12). They were either backward references or forward references, always within the 2000-2018 timeframe. A total of 66 papers were reviewed.

The papers were analysed and synthesised using text-coding and a thematic analysis based on the research questions (Paillé and Mucchielli 2009). Each text sample linked to a theme was coded and served as a basis for the results' presentation.

Furthermore, in a general analysis, the publication year, title, authors, journal, country of origin of the first author (university of origin), field of transport (freight, road infrastructure, train

infrastructure, general policy) and the inclusion of a case study were noted for each paper. For case studies, the type of decision (operational, tactic or strategic), which MCDA method was used and whether the CBA monetised environmental or social aspects were recorded. The papers were then sorted into four categories (Fig. 1). A small number of papers were assigned to two categories (n=8).

Moreover, papers considering explicitly or implicitly sustainable transport were identified among the selected papers. The papers were analysed according two themes: involving stakeholders in the decision process and having a holistic vision, which was further split into three sub-themes following Holden et al.'s (2013) definition: long-term ecological sustainability, satisfying basic human needs and intra and inter-generational equity.

Comparison papers were further sub-classified into two categories: (1) papers highlighting the differences in the results obtained when both methods were applied to the same project and (2) papers that present the strengths and the weaknesses according to different points of view (infrastructure, equity, policy, etc.). For the first category, the differences in the results were identified and the reasons explaining these differences were analysed. As for the second category, the strengths and the weaknesses as perceived by the authors were recorded and grouped according to different themes (e.g. transparency, simple to understand and ethical consideration).

Combination papers refer to papers that propose to combine CBA and MCDA in a new assessment framework. Four types of combination frameworks were identified in the literature (Fig. 2). Two papers were classified into two categories, and two papers mentioning methods combination were not explicit enough to allow for the identification of one of the four frameworks. For each combination paper, the reasons behind adopting a combination framework rather than a CBA or MCDA method, as well as the justification for using one of the four combination frameworks were recorded. Papers that did not include or were not explicit enough about these two elements were excluded.

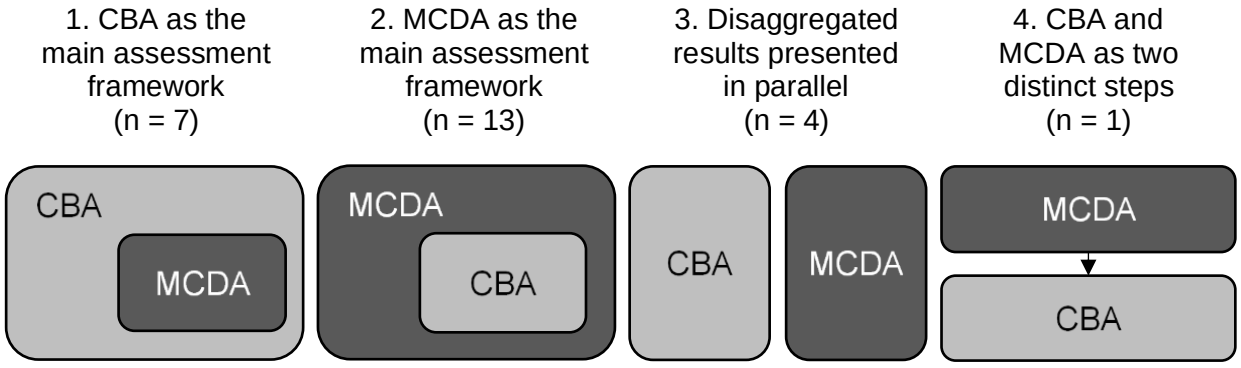

Fig. 2: Conceptualisation of the different frameworks to combine CBA and MCDA

As for the papers that focus on MCDA and mention CBA, and papers that focus on CBA and mention MCDA, they were either case studies or in-depth reflection about practices, processes or theoretical problems of a method. For case studies, the reasons why one method was preferred over another were noted. As for reflection papers, the strengths and weaknesses cited were added to the ones identified in the comparison papers according to the same themes used for comparison papers.

4 Results

Section 4.1 presents the results of the general analysis of papers on MCDA and CBA. Section 4.2 to 4.5 presents the strengths and weaknesses of CBA and MCDA as identified in the literature.

4.1 General analysis

Out of the 195 papers identified, 66 were reviewed. At least one paper on the subject was published per year and a slight increase of the number of published papers can be seen in the last five years (2014-2018 (n=26)) compared to the two previous five-year periods (2003-2007 (n=15) and 2008-2013 (n=18); Fig. 3).

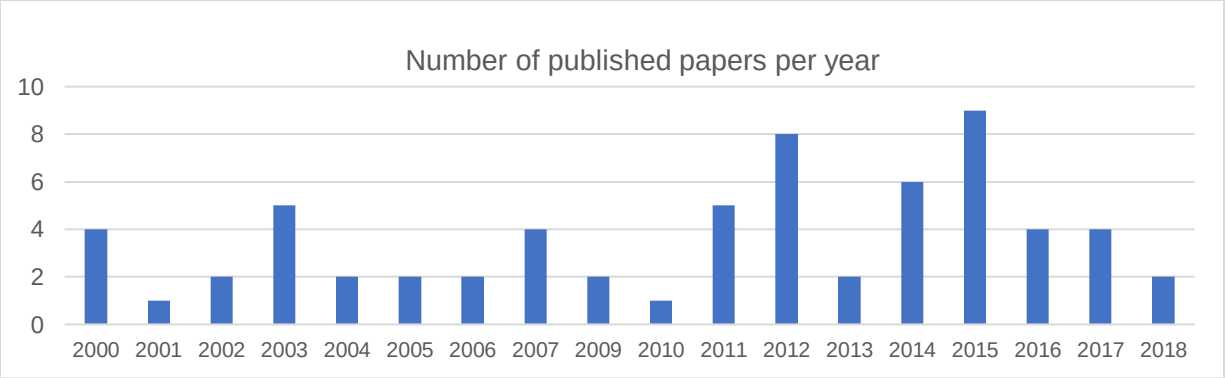

Fig. 3: Number of published papers according to the year of publication

42 papers included case studies. The majority of papers that developed a combination framework (23/25) or were centered on MCDA (16/20) were case studies; whereas the majority of comparison papers (11/15) and papers focusing on CBA (8/10) did not include a case study. Most of the case studies were applied for strategic decisions (38 out of 42) and no case studies involved operational decisions. AHP was the most frequently used method (n=15) and was often combined with other methods (n=12). Case studies that used a form of multi-attribute utility/value theory were also frequent (n=12). However, few case studies used outranking methods (n=3). As for case studies that included a CBA, 16 out of 25 monetised environmental or social aspects.

Moreover, 23 papers explicitly included sustainability considerations (either sustainable transport or sustainable development applied to transport) and 10 included these considerations implicitly. The majority of paper focusing on CBA did not include sustainability (8/10) and no trend for the other category of papers were identified (comparison papers, combination papers and MCDA focussed papers). Tables S-1 to S-4 present the full results of this general analysis in the supplementary material.

4.2 Comparison between the methods

Based on the papers that compared both methods, sections 4.2.1 to 4.2.4 present the strengths and weaknesses of CBA and MCDA as identified in the literature. Table 1 summarises the perceived strengths and weaknesses of CBA and MCDA.

As for the papers that compare the differences in results when CBA and MCDA were applied to the same project, two papers were identified in the literature: the resulting 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 for 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, which translated into a weight shift from the

CBA parameters to the MCDA parameters for the noise and visual impacts. As for Leviakangas et al. (2002), they explained the differences by observing that CBA was not flexible enough to assess new kinds of transport such as intelligent transport systems, a limitation that was not observed through their application of MCDA.

Table 1: Summary of the perceived strengths and weaknesses of CBA and MCDA

	CBA	MCDA
Strengths	• Rigorous process • Achieves different roles • Common language • Economic efficiency driven • Transparent • Reflects the values of "all" people	• Inclusion of stakeholders • Integrates qualitative and subjective aspects • Importance of process over results • Objectives driven • Variety of methods • Transparency of the process
Weaknesses	• Ethically dubious • Lack of transparency • Incorporating impacts that are not, or are difficult to monetise • Difficulty to deal with equity • Inclusion of stakeholders • Individual values versus collective values • Strategic behaviours	• Qualitative and subjective assessment • Issues about weighting • Subject to creating a "black box" effect • Double counting • Time and resources consuming • Forces the consensus

4.2.1 CBA perceived strengths

As the most used assessment method in practice, CBA has evolved and has been adapted to new considerations over the years. The assumptions and theory underlying CBA (social welfare theory, WTP, hedonic prices, etc.) are well-known, have been analysed and debated through the years and are now formalised under various norms, guidelines and structured frameworks (Damart and Roy 2009; Beria et al. 2012; Dimitriou et al. 2016). This formalisation has led many to perceive CBA as a "neutral", rigorous, transparent and formal method since it allows its users to compare clearly and precisely the costs and the benefits translated into monetary terms (Browne and Ryan 2011; Beria et al. 2012; Babashamsi et al. 2016; Hickman and Dean 2017). This is particularly the case for "hard" effects that are quantifiable and measurable in monetary terms (e.g. construction and maintenance costs) or where assumptions are made that make it possible to measure impacts in monetary terms (e.g. benefits to freight transport, travel time savings). According to Nadafianshahamabadi et al. (2017), the use of CBA can help prevent the implementation of transport projects that may have negative impacts on the social welfare. It can also increase the legitimacy of a process that is highly political by making an objective quantification of economic impacts.

Despite the perception of neutrality and objectivity, the role of CBA in the transport decision process may vary. Sometimes, CBA is a decision-making method with a prescriptive role: a project should only be done if the NPV is positive or if the BCR is higher than 1 (Beria et al. 2012). Other times, CBA acts as a decision aiding method with an informative role similar to a survey of wider societal impacts, in which case the NPV or BCR play a less significant role in the decision process. As a consequence, CBA provides a global picture of a situation and in an iterative process, can help to generate improved alternatives by identifying the pros and cons of existing alternatives (Jong and Geerlings 2003; Rudolph et al. 2015).

It is generally accepted that the common language used in CBA, i.e. monetary terms to express the various impacts across time and space, facilitates communications to decision-makers and public authorities. Moreover, the use of a normalised approach to monetise impacts allows for comparability between projects. According to some authors, notwithstanding the transport modes (bus, rail, car, bicycle) or the regional contexts (urban, suburban, rural), the projects can always be compared (Hickman and Dean 2017; Cornet et al. 2018).

One of the most frequently cited strengths of CBA (12 out of 19 comparison papers) is that it highlights economic efficiency and welfare impacts. Governments have restricted budgets and therefore must choose the alternative that will create the most advantages and cost the least. It must be evident that the efforts are worth it (Hüging et al. 2014).

Since CBA is market-driven, its results reflect the values of "all people" as the monetary values are defined according to the individuals' preferences through willingness to pay or observed behaviour (Bristow and Nellthorp 2000; Weisbrod and Street 2011; Dimitriou et al. 2016). It can even be considered an "economic democracy" where individuals express their preferences with their money ("vote") and, if they lose, the monetary gain compensates for the loss. This is different from a political democracy where individual that "lost their election" have to accept the vote of the majority without compensation (Munda 2017).

4.2.2 CBA perceived weaknesses

The costs and benefits that are traditionally included in a CBA aim at estimating the efficiency of a transport project. CBA is excellent for incorporating economic factors. However, despite the development of different techniques to monetise non-monetary and qualitative aspects, the emphasis of CBA on monetary aspects tends to ignore or underestimate environmental, social and strategic impacts that are relevant to sustainable transport (Salling et al. 2007; Salling and Pryn 2015; Cornet et al. 2018). This restricts CBA to a narrower vision of project impacts and may create bias toward specific transport projects. This concern was identified in a survey addressed to Dutch politicians by Annema et al. (2015) where politicians acknowledged that CBA results are incomplete and expressed interest in a more global project vision.

Generally, there is a consensus among economists about the direct economic impacts that should be included in transport project assessment, but which intangible and non-direct economic aspects should be included and how they can be monetised is still highly debatable (Beria et al. 2012; Annema et al. 2015; Babashamsi et al. 2016). The development of social CBA was aimed at addressing this issue. However, according to some authors, determining the monetary value through WTP is hard, subjective and may vary in different social contexts (De Brucker et al. 2004; Damart and Roy 2009; Thomopoulos and Grant-Muller 2013). For example, it has been shown, through revealed preference studies, that a WTP linked to CO2 emissions can vary significantly depending on how the information is framed (e.g. from $0/tonne to nearly $400/tonne of CO2 emissions; Daziano et al. 2017). In addition, the monetisation of every impact (quantitative non-monetary and qualitative) raises several ethical considerations. It must be assumed that everything can be valued with money, including environmental, security and health aspects, which may be perceived as an immoral practice by some (Browne and Ryan 2011; van Wee 2012; Hüging et al. 2014; Dimitriou et al. 2016; Hickman and Dean 2017). For example, in a survey addressed to different Dutch professionals involved in the transport field, Mouter et al. (2013) showed that some aspects like travel time saving and biodiversity were deemed incomparable by urban planners, but totally comparable by economists.

Moreover, in a CBA, despite a population's sensitivity to environmental issues, travel time-saving benefits often highly compensate the negative environmental consequences (Kelly et al. 2015; Hickman and Dean 2017). In fact, since travel time gains represent the majority of benefits (between 50 % to 90%) according to Mackie and Nellthorp (2001), Gwee et al. (2011), and Browne and Ryan (2011), this may lead to discarding transport projects such as public transit or cycling infrastructure that have only small gains or losses in time gains, but that have other benefits, harder to measure. Consequently, this favours projects that encourage longer travel distances (e.g. expanding or building new highways) which is in clear contradiction with the sustainable transport objective of reducing travel distance and reducing land consumption (Hickman and Dean 2017). All these aspects make the CBA results potentially subject to interpretation and prevent decision-makers from fully understanding the different impacts and the trade-offs between impacts. As pointed out by Mouter et al. (2013), the counter effect of this situation on decision-makers is to assign either too much or too little value to CBA results.

Although the translation process of impacts in monetary terms may be clear for experts and some decision-makers, the complex calculations and the underlying hypotheses can render the outcome non-transparent and difficult to understand for other stakeholders. This process can reduce political issues to a technical debate that only transport experts can fully comprehend (Damart and Roy 2009; Hickman and Dean 2017). In fact, Beukers et al. (2012) showed that stakeholders using CBA, but not directly involved in the CBA process (planners, advisors, lobbyists), perceived CBA as a black box. In fact, the NPV and BCR summarise the information in one number, and CBA reports are not explicit enough about the compensation that occurs between impacts (e.g. natural capital being completely replaceable by human capital). For example, some economists have concluded that mobile phones should not be banned while driving because the cost of compensating all drivers using their mobile phone (consumer surplus) would be higher than the monetary gain linked to the decreased risk of (the relatively infrequent) accidents and fatalities (Hahn and Tetlock 1999; Redelmeier and Weinstein 1999).

As mentioned, a clear CBA limit identified in the literature is the problem of including equity principles. Traditionally, CBA does not consider the distribution of the increase in welfare among various socio-economic groups and different regions. The aggregation of gains and losses in one value undermines the capacity to clearly identify the winners and the losers in the process; a transport project could easily favour wealthier groups (or regions) at the expense of lower income groups (or regions) and reinforce inequities (van Wee 2012; Martens 2016; Hickman and Dean 2017). An equal value for travel time gain is often assumed to counter this effect (e.g. the average monetary value of travel time of commuters in the United States is of 12 $/h, irrespectively of an individual's hourly income; Mackie et al. 2014). This is viewed as a partial solution by Nahmias-Biran and Shiftan (2016). A possible improvement is to use a distribution matrix that informs decision-makers of the consequences of each alternative on each stakeholder or to allocate different weights to different socio-economic groups (Beria et al. 2012; Munda 2017). Nonetheless, few CBA guidelines include equity distribution in practice, with Germany being one of the exception (Bristow and Nellthorp 2000).

Equity over time is another concern. The use of discount rates reduces long term impacts to a value of almost zero which results in disadvantages for future generations and a disequilibrium between short and long-term social and environmental impacts (Dimitriou et al. 2016; Hickman and Dean 2017; Cornet et al. 2018). An environmental impact could take several decades before it manifests (loss of biodiversity, water quality degradation, climate change) and go way beyond the usual

reference period considered in CBA (i.e. between 20 and 60 years), which makes future generations voiceless (Nadafianshahamabadi et al. 2017; Hickman and Dean 2017). Furthermore, the range of discount rates used for transport projects in different countries is a sign that there still is no consensus on how to deal with long-term impacts in CBA (Gwee et al. 2011). Therefore, some authors argue that the choice of a discount rate and a reference period are value judgements making it difficult to claim that CBA is objective from a positivist point of view (Nadafianshahamabadi et al. 2017).

The inclusion of stakeholders and of collective values in the decision process is also difficult in a CBA (Damart and Roy 2009) since it cannot consider public debates surrounding a transport project and may thereby increase controversies at later stages of the project (Dimitriou et al. 2016; Hickman and Dean 2017). For example, Beukers et al. (2012) showed that the lack of discussion between stakeholders regarding the assumptions used in the CBA creates a gap and a communication deficit between planners and economists.

The Hicks-Kaldor principles, on which CBA is based, assume that people act as individual consumers who behave rationally (by maximising their welfare) with no regards to collective issues. Sustainable transport requires the consideration of issues that are larger than individuals and that affect society as a whole and is often considered a tragedy of the commons' problem (Brown et al. 2019). Basing monetary values on individual preferences may go against societal interest in the long term (Damart and Roy 2009). For example, it is not because someone does not use a service that the person does not value this service (e.g. someone might still value having bus service in a city, without necessarily being a bus user; van Wee 2012). Therefore, public policy cannot rely only on the aggregation of individual preferences or willingness to pay in order to make a decision (Munda 2017).

The obligation to apply CBA to some projects and its use as a decision-making method rather than as a decision-aiding method creates strategic behaviours. For example, it was reported in the transport infrastructure literature that some decision-makers and practitioners deliberately underestimate costs and overestimate benefits to facilitate projects implementation (e.g. strategically selecting favourable unit values or scenario assumptions; Flyvbjerg et al. 2002; van Wee 2012; Kelly et al. 2015). This might happen when CBA is introduced at a too advanced stage of the planning process to act as a decision aiding method, because the decision has already been made. Consequently, the obligation to conduct a CBA is sometimes perceived as a hurdle that must be overcome in order to get funding for a project, rather than a method to improve the project and the decision process (Beukers et al. 2012; Kelly et al. 2015). For example, if CBA outcomes align with the political interests, the method's limitations will be ignored, whereas when CBA results do not support the political interests, the limitations will be highlighted (Mouter et al. 2013).

4.2.3 MCDA perceived strengths

Since MCDA is objectives driven, all aspects that matter can possibly be assessed, including those that are intangible, qualitative and non-monetary quantitative (Griskeviciute-Geciene 2010; Hüging et al. 2014; Annema et al. 2015; Nadafianshahamabadi et al. 2017). MCDA goes beyond economic efficiency; it does not require assigning monetary values to positive or negative impacts in order to properly assess projects (Thomopoulos and Grant-Muller 2013; Cornet et al. 2018). It can inform decision-makers of the degree to which an alternative achieves policy objectives, such as the ones defined in a sustainable mobility plan, and show the trade-offs between the different objectives (Tudela et al. 2006; Weisbrod and Street 2011). From a sustainability perspective, showing the achievement of policy objectives is insightful since it gives a more holistic and

multidisciplinary perspective on projects (Browne and Ryan 2011; Hüging et al. 2014; Dimitriou et al. 2016). One such objective is equity. The Sustainable Mobility Inequity Indicator (SUMINI) is a MCDA appraisal method that was specifically designed by Thomopoulos and Grant-Muller (2013) to complement current project assessment methods. It considers five types of equity (i.e. horizontal equity, vertical equity, environmental equity, regional/spatial equity and accessibility). It is an informative method since it highlights which types of equity are enhanced or deteriorated by a given project.

Among its other identified strengths, MCDA is perceived to facilitate the inclusion of stakeholders (e.g. decision-makers, experts, citizens, etc.) in the decision process (Annema et al. 2015). The stakeholders' participation may take different forms: individual interviews (Scannella and Beuthe 2003), online surveys (Spiekermann and Wegener 2004; Thomopoulos and Grant-Muller 2013; Nadafianshahamabadi et al. 2017), the Delphi method (Kang and Lee 2007), group workshops (Marleau Donais et al. 2019), decision conferencing (Barfod et al. 2011; Barfod and Salling 2015) renamed planning workshop when it only includes experts and no decision-maker (Barfod 2018), or a mix of interviews and surveys (D'Este 2009; Cornet et al. 2018). This can be a factor of success as it articulates the issues and objectives of the stakeholders who, otherwise, would not have been considered (e.g. landscape, noise impacts; Tudela et al. 2006). Using a deliberative process among stakeholders, MCDA can develop a consensus to resolve conflicts and to propose a solution that reflects the preferences of the involved individuals and groups (De Brucker et al. 2004; Browne and Ryan 2011; Hüging et al. 2014). Moreover, the expression of these preferences according to transport policy objectives adds transparency and can contribute to explaining the rationale behind the choices made (Thomopoulos and Grant-Muller 2013; Munda 2017).

As a way to include stakeholders with divergent values and preferences, multi-actor multi-criteria analysis (MAMCA) is a method developed specifically in the transport field that was used in three different reviewed papers (Macharis et al. 2014; Balm et al. 2016; Cornet et al. 2018). This method builds a MCDA model according to the values and preferences of each stakeholder group (e.g. users, public transit operators, local governments and federal government) to show the trade-offs and conflicts that may occur between the various groups. Cornet et al. (2018) proposed to penalise alternatives that have diverging viewpoints within groups compared to alternatives that are more consensual. Bana e Costa (2001) developed such a method for investment policy in new intermunicipal road links by analysing conflicts between stakeholders regarding the alternatives and, in an iterative process, developed new alternatives that were collectively more attractive.

Several of the papers recognise that MCDA is not a decision-making method, but a decision process that aids to structure the decision. It is not the result that matters, but the process leading to the decision that makes a project successful (Spetzler 2007; Browne and Ryan 2011). From a MCDA perspective, it is difficult to qualify a decision as good or bad only on the basis that a mathematical model is valid and accurate (Munda 2017). As a matter of fact, the problem structuring nature of MCDA often allows the transformation of an ill-defined problem (which is usually the case for sustainable transport) into a set of structured relations and criteria. At the early stages of projects, it helps the involved stakeholders to learn about other stakeholders' objectives, to give a wider perspective on the problem, to develop alternatives that may better achieve their objectives and to identify the uncertainties surrounding the decision process (Bristow and Nellthorp 2000; Galves 2005; Gamper and Turcanu 2007). Thus, it makes complex situations more transparent and facilitates the choice of an alternative that strikes the right balance between the various and often conflictual objectives (Dimitriou et al. 2016).

4.2.4 MCDA perceived weaknesses

MCDA has been subject to several criticisms namely that of being arbitrary, subjective and having a black box effect (D'Este 2009; Quinet and Meunier 2012). The involvement of stakeholders in the construction, with a facilitator, of the MCDA model parameters (e.g. criteria, weights, value function, threshold) is perceived as a subjective process (in a positivist paradigm) which in itself, is both a strength and a weakness (Hüging et al. 2014; Bueno et al. 2015; Nahmias-Biran and Shiftan 2016; Hickman and Dean 2017). Subjectivity is negatively perceived in decision processes because of the lack of procedures and norms to obtain parameters (Sayers et al. 2003), of the lack of transparency regarding how parameters are elicited (Browne and Ryan 2011) and because it is susceptible to biases since parameters are based on the preferences of the involved stakeholders (often decision-makers or experts). Therefore, the selection of the stakeholders involved in the process may have a great influence on the results since stakeholders have different expertises and values. It could lead to different rankings depending on the group's composition (Gamper and Turcanu 2007; Annema et al. 2015; Babashamsi et al. 2016; Nahmias-Biran and Shiftan 2016; Nadafianshahamabadi et al. 2017).

Moreover, certain stakeholders may dominate during group workshops and the presence or absence of stakeholders at workshops can have an impact on the final outcomes (Rudolph et al. 2015; Marleau Donais et al. 2017). Some stakeholders could also have a hidden agenda and provide biased information or may be reluctant to share knowledge or power with other stakeholders during group workshops (Gamper and Turcanu 2007). The MCDA process works well when stakeholders have similar sets of objectives, but it can pose quite a challenge when the objectives are different or even conflictual. Therefore, aiming for a consensus could force a result on the stakeholders and lead to a loss of richness and viewpoints (Hüging et al. 2014). Also, forcing the consensus through weighting or aggregation could dissatisfy some stakeholders and raise suspicion toward the process (D'Este 2009). A study about a highway project in Tehran, Iran (Nadafianshahamabadi et al. 2017) and a study about freight distribution in Thessaloniki, Greece (Macharis et al. 2014) have shown how stakeholders with different technical knowledge and values ultimately led to favour distinct projects. The question of how to best handle different values is still unclear; a debate between the various stakeholders perspectives must take place and the use of, an often meaningless, mathematical average is perceived as problematic (Hickman and Dean 2017). Consequently, stakeholder interactions, discussions and debates can render the decision process more time and resources consuming. Furthermore, it requires that all key stakeholders be gathered, which can be difficult and costly to achieve (Gamper and Turcanu 2007; D'Este 2009).

On a different note, the complexity of mathematical procedures that are sometimes required, in order to aggregate the alternatives' performances over many criteria, was identified as another weakness. This perceived black box effect can make it difficult for non-technical decision-makers and stakeholders to understand how MCDA arrives at the results (Griskeviciute-Geciene 2010; Browne and Ryan 2011). In addition, according to Browne and Ryan (2011), the use of single-synthesising criterion methods allows, as with CBA, to aggregate aspects that might be incomparable. This creates a loss of information and hides the trade-offs that might occur between criteria performances. A black box effect can also be created when the MCDA results are locked within software to which stakeholders have no access or that is not user-friendly (D'Este 2009).

Furthermore, the possibilities of double-counting impacts when criteria are loosely defined within a MCDA are perceived as undesirable since the effects considered in the set of criteria can be unclear and inconsistent. A special care is needed to avoid such situations that create bias in

assessment (Scannella and Beuthe 2003; Beria et al. 2012; Annema et al. 2015; Nahmias-Biran and Shiftan 2016).

4.3 Combination of Methods

In order to resolve some of the issues with CBA or MCDA, some authors have suggested combining both methods into a new framework; the term hybrid model is also found in the literature. The combination of MCDA and CBA usually refers to three different steps : (1) using CBA to measure monetary impacts (e.g. infrastructure cost, operating cost, travel time), (2) using MCDA to measure quantitative non-monetary and qualitative impacts (e.g. land-use planning, accessibility, equity distribution) and (3) combining the results of the CBA part and MCDA part according to different frameworks. However, what is considered as a monetary impact varies depending on the author. For example, some authors monetised air pollution and noise and included the impacts within the CBA part (Bekefi et al. 2003; Leleur et al. 2007; Chen et al. 2008; Gühnemann et al. 2012; Shiau 2014), whereas other authors kept these impacts in their original units and included them in the MCDA part (Panou and Sofianos 2002; Hüging et al. 2014; Macharis et al. 2014; Salling and Pryn 2015).

4.3.1 Reasons to Combine CBA and MCDA

Authors suggesting a combination of the two methods find that traditional economic analyses, such as CBA, are too narrow, provide limited information to the decision-makers and do not capture all decision criteria (Leleur et al. 2007). The best CBA solution may be the most efficient economic solution, but it may be in conflict with sustainable transport objectives and lead to a project that is not the most advantageous from this new perspective (Prokopowicz and Dabrowska 2016). Hence, for these authors, the combination of CBA with a MCDA can overcome such CBA limitations by including all of the essential aspects and the various stakeholders' perspectives in the decision process. Moreover, the combination of both methods allows to handle sustainability in several ways: it eliminates the hurdles related to the integration of non-monetisable, non-quantitative or intangible aspects (Ambrasaite et al. 2011; Gühnemann et al. 2012); it better copes with complex problems linked to sustainable transport by giving a more holistic and multidisciplinary perspective (Salling and Pryn 2015); it takes into account equity concerns and a better distribution of impacts (Thomopoulos and Grant-Muller 2013); it includes governmental objectives of sustainability and sustainable transport and it aids with choosing projects aligned with these governmental objectives (Salling and Landex 2006; Gühnemann et al. 2012). Consequently, CBA and MCDA are not seen as competitors, but as complementary since, together, they provide the global picture and therefore potentially improve decisions.

Few criticisms have arisen of the combination of CBA and MCDA, though this may be due to it being too recent. The only identified criticism is that the combination of two complex methods may further complicate project appraisal and create a bigger black box effect for decision-makers (Annema et al. 2015). As pointed out by Mouter et al. (2013), further research is required regarding the perception of the advantages and disadvantages of combining CBA and MCDA.

The following sections (4.3.2 to 4.3.5) present in further detail the different combination frameworks and the rationale behind choosing a specific framework. Although the reasons were often numerous, the authors were not always explicit in their justification and did not state their reasons for choosing a framework.

4.3.2 Framework with CBA as the main method and MCDA as a component

In the few combined frameworks proposed where CBA is the main method, the aim was always to add the MCDA-criteria to the CBA-impacts. The most frequent framework in the literature is COSIMA (5 papers out of 7) which converts the MCDA results with a calibration factor to express the trade-off between the CBA part and the MCDA part, and then calculates a total return rate. The calibration factor is determined by using shadow pricing methods such as WTP for the MCDA-criteria (Salling and Landex 2006; Leleur et al. 2007; Salling et al. 2007; Ambrasaite et al. 2011; Barfod et al. 2011). COSIMA's authors preferred this type of combination because it can include wider impacts and present the results to the decision-makers in a total return rate similar to CBA, a language with which, according to the authors, decision-makers are familiar. One of the other frameworks with CBA as the main method is Strategic Options Assessment (SOA) that uses an extension of the Australian adjusted CBA and weighs spatially or temporally the monetary values according to policy objectives. For example, if the objective is to support urban renewal, a higher score will be given to the future benefits that have implications in the identified renewal area (Prosser et al. 2015). This framework is perceived as safeguarding the rigour of CBA while retaining the flexibility of MCDA.

4.3.3 Framework with MCDA as the main method and CBA as a component

Other authors have suggested frameworks where MCDA is the main method. 13 such papers were identified in the literature. They rely principally on the idea that CBA results should be considered as a single criterion (cost or economic efficiency) to be included in a MCDA (Tsamboulas and Mikroudis 2000; Barfod and Salling 2015). Some authors also perceived that MCDA is easier, more practical and better takes into account local issues by measuring the objectives' degree of achievement. Interestingly enough, the COSIMA method was recently disavowed by some of its creators because they judged it too difficult to apply in practice. They suggested that including CBA results within a MCDA 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 and Salling 2015; Salling and Pryn 2015)

4.3.4 Framework with disaggregated results in parallel

As another alternative, some authors prefer to present, side by side, disaggregated results of CBA and MCDA (4 papers). The perceived complementary nature of CBA and MCDA implies that they should not be aggregated and that their results represent two distinct sets of values (i.e. CBA represents consumer values whereas MCDA represents decision-maker values; Macharis et al. 2014; Balm et al. 2016). Furthermore, the presentation of results in parallel allows decision-makers to understand how the impacts are distributed, what are the trade-offs and who are the losers and the winners. It also avoids double-counting effects that could occur when combining the two methods (Spiekermann and Wegener 2004).

4.3.5 Framework with MCDA and CBA as two steps

Finally, the methods can be combined as two different steps in the assessment process. Only one such paper was identified in the literature. This type of combination was chosen because CBA is perceived as mathematically more rigorous, but with a narrower vision than MCDA. In a first step, MCDA allowed for a larger set of alternatives to be screened according to a holistic vision and to choose 2 or 3 alternatives that would be examined in further detail in a second step with CBA (Rogers 2000). In other words, MCDA allows the alternatives to be assessed at a strategic level (how it relates to policy objectives) whereas CBA assesses the alternatives at the project level (the financial costs and benefits of implementing the projects).

5 Discussion

5.1 Comparing CBA and MCDA from a rationality perspective

The comparison of CBA and MCDA in the field of transport has shown that both methods have perceived strengths and weaknesses, and that what is viewed as a strength by one author could, at the same time, be considered a weakness by another. The rigour of CBA to assess projects in terms of economic efficiency is praised whereas the flexibility of MCDA to take into account a wide array of qualitative and quantitative criteria is recognized. However, CBA is considered as both transparent and non-transparent and MCDA's inclusion of subjective and qualitative aspects is deemed both a strength and a weakness.

The contradictions identified above may be explained by the different ways of conceptualising rationality and the decision aiding approaches of Meinard and Tsoukias (2018). In the reviewed papers, most of the arguments in favour of CBA are linked to an objectivist approach. CBA is usually conducted according to predefined norms or guidelines with an aim of economic efficiency (i.e. an unquestionable formulation of the problem that is independent from the context). Since CBA is based on the Hick-Kaldor principle, a "good" solution will be the one with the most favourable benefit-cost ratio (BCR). However, a CBA that will deviate from the guidelines in calculating the BCR or a decision that will not choose the solution with the best BCR will be considered as illegitimate (i.e. non-acceptable in a particular organisational context; Landry et al. 1996). In an objectivist approach, integrating subjective aspects should be avoided and is considered a weakness. This may explain some of the strategic behaviours adopted by certain stakeholders who alter results in order to implement transport projects that would be, without alteration, illegitimate from an objectivist approach (Flyvbjerg et al. 2002). In addition, several of the arguments against MCDA are justified in an objectivist approach. The ill-defined nature of multicriteria problems (i.e. problems must be structured according to the context) with only satisficing solutions and no optimal solution is in contradiction with an objectivist stance. In MCDA, norms and guidelines hardly exist since the different parameters used usually reflect stakeholders' values.

Conversely, several of the arguments identified in the transport literature in favour of MCDA are related to an adjustive approach or a reflexive approach. For example, the inclusion of stakeholders in the process and the elicitation of their preferences, values and needs according to the specificity of each problem is in line with an adjustive approach where the inclusion of subjectivity is viewed as a strength. The tendency in MCDA to grant more importance to the process than to the results is in line with a reflexive approach. In fact, some MCDA processes will structure an ill-defined problem according to objectives, behaviours and inner preferences that are constructed through the process. In addition, several criticisms addressed to CBA are linked to an adjustive approach (e.g. non-transparency, trying to monetise every impact and concerns about collective values). From an adjustive perspective, if the elicited preferences contradict the norms, it is because the norms are ill-conceived. Consequently, if economic efficiency does not reflect the stakeholders' preferences in a specific context (e.g. equity, environmental protection, accessibility), then CBA is not suitable for the project.

However, as pointed out by Tsoukiàs (2008), it is not the method that defines the decision approach, but rather how rationality is conceived of and how the decision process is conducted. For example, in reaction to criticism of MCDA's subjectivity, Salling and Pryn (2015) adopted an objectivist approach to MCDA where the weights between the sustainability dimensions are predefined according to the nested model for sustainability (i.e., environment is more important

than social, which is more important than economic) and the weights between criteria within a dimension are all the same. Nonetheless, the use of such an objectivist approach disregards some of MCDA's advantages such as problem structuring and stakeholders' involvement.

5.2 On the combination of CBA and MCDA in transport

The study of the various combination frameworks in transport shows that there is still no consensus on how MCDA and CBA should properly interact. Despite the common goal to include a larger set of impacts in project assessment, different authors had different justifications for choosing a given framework over another. Nonetheless, the recent shift by some authors (Barfod and Salling 2015; Salling and Pryn 2015) from CBA toward MCDA as the main method in transport, illustrates that CBA may be difficult to apply in practice. Still, the combination of both methods does not exactly fit one of the four decision-aiding approaches proposed by Meinard and Tsoukiàs (2018) and, depending on the context and the stakeholders, the combination could be applied according to different approaches.

5.3 Integrating sustainable transport in project assessment

The inclusion of sustainable transport in project assessment raises the question of whether current evaluation methods allow these new principles to be integrated. As is recommended by Gudmundsson et al. (2016) project assessments geared toward sustainability should have a holistic vision and include stakeholders in the decision process. No matter the method, sustainable transport can be considered within different decision-aiding approaches. For example, sustainable transport could be considered in project assessment as the only objective truth to follow (objectivist approach), as norms and behaviours expected to apply in practice (conformist approach) or as the inner stakeholders' preferences and values (adjustive approach). CBA is an appropriate method when the aim is to choose a project with the objective of economic efficiency. However, in light of the weaknesses highlighted in the previous sections, CBA poorly takes into account several aspects inherent to sustainable transport. Despite the recent developments to include non-monetised impacts, the assumptions on which CBA is based are in conflict with the objectives of sustainability. Sustainable transport requires projects to be assessed from a collective perspective rather than from an aggregated individual perspective as suggested by social welfare theory. It also needs to consider long-term impacts on the society and the environment; two aspects that usually have a weak voice in CBA (due to future discounting), when they are not totally ignored.

MCDA, given its more flexible nature, can more easily include various aspects to form a holistic vision and to integrate stakeholders in the decision process. Depending on the project, it can inform stakeholders of the degree of fulfilment of the different objectives toward sustainable transport and identify the alternative that best suits a problem. However, as pointed out by Bueno et al. (2015), despite MCDA's potential to take into account sustainability, it is not necessarily the case in practice. For example, MCDA does not always consider a life-cycle approach of impacts (i.e. considering impacts over the whole life-cycle from the conception to the end of life processing; Bueno et al. 2015) or can sometimes include experts or decision-makers in the decision process and exclude other stakeholders (Tsamboulas and Kopsacheili 2003; Spiekermann and Wegener 2004; Barfod and Salling 2015; Cornet et al. 2018). Moreover, despite the claim of several papers that stakeholders were included, there were case studies that did not explicitly report how or which stakeholders participated in the decision process (Anagnostopoulos et al. 2001; Panou and Sofianos 2002; Salling et al. 2007; Tischler 2017). This raises a concern since developing models that are theoretically valid, but that are only tested in fictive case studies is only a first step in the right direction. These models must ultimately be applied in practice with real stakeholders to assess how they perform in the real world, if they are to have any valuable contribution.

5.4 Limits of this Study

To ensure the quality of this literature review, Templier and Paré's (2018) guidelines were followed: the research questions and key concepts were clearly stated; the literature search and screening process were defined; the data extraction methods according to the different categories of papers were described and the results were analysed. However, this literature review is not without limits. The inclusion of both CBA and MCDA as keywords in the databases seems to have created a positive bias toward papers related to MCDA. More papers focussing on MCDA were identified in the review than papers centred on CBA. More specifically, the abstracts of papers that focus on MCDA were usually positioned in opposition or as a complement to CBA. This situation seemed less common in papers that emphasize CBA (as it is often the standard or norm). To counterbalance this effect, cross-referenced papers about CBA were thoroughly searched.

Furthermore, the search was limited to English databases, indexing journal and conference papers and excluded reports, books and grey literature. Also, data extraction was based on text coding of the papers according to various analysis themes as described in the methodology, which is a subjective process. Despite these search limitations, a redundancy in the arguments and the points of view were observed in the results and the analyses of the retained papers. This leads us to believe that the full spectrum of reported weaknesses and strengths of both methods in the field of sustainable transport were covered. The inclusion of other documentation in the literature review would not necessarily have contributed new answers to our research questions.

6 Conclusion

The aim of this paper was to better understand the perceived strengths and weaknesses of CBA and MCDA methods in the field of transport, to analyse the different ways to combine them and to further analyse if and how they have the capability to better include sustainability in transport. To answer our research questions, a systematic review of papers in four distinct databases was achieved, the papers were text coded according to various themes and the results for each theme were analysed. In addition, the two methods were analysed with respect to four different decision-aiding approaches (objectivist, conformist, adjustive and reflexive) to further comprehend the distinct conceptualisations of rationality of what make a "good" decision.

The results showed that both methods have strengths and neither are exempt from weaknesses; different decision-aiding approaches influence the positive or negative perceptions of how methods are applied. In any case, the use of one method or the other will always improve decision-making relative to unaided decision-making (Hajkowicz 2007). The combination of both methods is a possible avenue to improve existing decision processes, but, in a context of sustainable transport, this combination has mostly served to solve problems inherent to CBA. Further research on this topic is required to analyse the pros and cons of combining both methods.

A strong focus during the comparison was set on how the methods included the principles of sustainable transport. The results showed that CBA is excellent for measuring economic efficiency, but lacks flexibility to appropriately consider aspects inherent to sustainable transport such as equity between social groups and over time, environmental impacts, or stakeholders' inclusion. As for MCDA, despite its weaknesses, our results have shown that it has the capability to consider quantitative and qualitative information and to include stakeholders from many different horizons. Therefore, in complex and uncertain environments such as sustainable transport, the use of MCDA or the combination of CBA and MCDA may be more suitable to decision-making processes than CBA alone.

In further research, it would be interesting to compare the different perceptions of MCDA and CBA and the various ways to combine them across various fields. This comparison could highlight similarities and/or divergences across fields. Moreover, the identification of practices developed in other fields where methods are combined could improve the general practices of CBA and MCDA in transport. For example, planning for resiliency allows transport networks and infrastructures to better recover following disasters and disruptions (Ganin et al. 2019). However, transport networks that are the most efficient and that minimize the travel time (which is usually the principal benefits considered in CBA) are not necessarily the ones that are the most resilient (Ganin et al. 2017). This raises several questions on how to consider resilience in project assessment in a context of climate change.

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