A LITERATURE REVIEW REGARDING THE APPLICATION OF MULTI-CRITERIA ANALYSIS IN TRANSPORT INFRASTRUCTURE PROJECTS

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Abstract

The evaluation, selection or prioritization of transport infrastructure projects requires a complex decision-making approach. This complexity arises due to the competing nature of criteria - socio-economic, technical, political, environmental, resulting often into conflict analysis (Thomopoulos et al., 2009). The purpose of this article is to review the available literature in order to identify the specific multi-criteria decision-making techniques/methods, as well as the criteria employed in the context of transport infrastructure. Moreover, as we were interested to assess if these criteria evolved along the time to meet the transport infrastructure policy goals, in the nowadays context of green transition a special attention is given to the environmental criteria and its indicators. The timing of this review, providing an overview of the criteria used for the assessment of transport infrastructure projects, seems to be suitable as the new European Union's Multiannual Financial Framework (2021-2027) is pushing forward for the twin green and digital transitions, enforcing the climate dimension. An extensive list of environmental indicators is provided, as well.

Keywords: multi-criteria analysis, transport infrastructure, criteria, literature review

1. INTRODUCTION

Transport infrastructure projects are known for being resource-intensive, capital included. As the public funds (and natural resources, in general) are scarce and need to be allocated in the most sustainable and efficient way, multiple infrastructure projects are found in a competing environment for being implemented. Identified as major contributors to economic growth, important factors for the social development, these projects come with a significant environmental footprint, mainly referred to from a negative impact's perspective (Nguyen et al., 2017, Broniewicz & Ogrodnik, 2020, Slimak & Zgodavova, 2011). Therefore, in a sustainable development framework, the focus should be rather on the social, environmental and institutional dimensions (the institutional dimension was presented by Ward et al. (2016b) as the fourth project pillar of the sustainability), let alone the economic and financial dimensions (UN Habitat, 2013 in Ward et al, 2016b). Moreover, the planning, selection, appraisal, ranking or prioritization of transport infrastructure projects are in the center of numerous and contradictory objectives sustained by multiple stakeholders (associations, NGOs, citizens, government, local authorities, etc.) (Zembri-Mary, 2017).

In this context, various decision-making methods were employed. Although a popular decision-making method applied for the evaluation of transport infrastructure projects, the Cost-Benefit Analysis (CBA) received

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numerous critiques especially because of the approaches employed to convert (qualitative) values, often expressed in different units of measurement into monetary terms, or of its narrower capacity to accommodate the entire policy or capital projects impacts into its framework (Iniestra & Gutierrez, 2002 in Deluka-Tibljas et al., 2013; Browne & Ryan, 2011 in Macharis&Bernardini, 2015). This limitation of focusing on the wider set of impacts is also attached to the Cost-Effectiveness Analysis (Browne & Ryan, 2011 in Macharis&Bernardini, 2015). Offering the possibility to include a larger array of criteria (monetary and non-monetary) and policy objectives and the possibility to integrate the stakeholders view in the assessment, Multi-criteria Analysis (MCA) became increasingly used (Deluka-Tibljas et al., 2013; Kabir et al., 2014; Ward et al., 2016a). Also, the MCA can be combined/integrated with the CBA, as pointed out in Macharis&Bernardini (2015), but with other methods as well, for example the Environmental Impact Assessment or Life Cycle Assessment, some of the tools for the assessment of the environmental footprint of (transport infrastructure) projects.

Acknowledged to be better-suited in the sustainability assessment context, due to its flexible framework allowing for the inclusion of the sustainability dimensions, multiple MCA techniques were used in the evaluation of transport infrastructure projects (such as AHP, ANP, TOPSIS, SMART etc.) (Bueno et al., 2015). Each of these MCA methods have their own particularity and are more appropriate to be employed, taking into account the specific situation that the decision-making approach should be applied to (Tsamboulas, 2007). Moreover, the criteria and their indicators (parameters that can be measured for each criterion), or even sub-criteria, varies not only in terms of their number included in the assessment, but also in terms of their definition. There is no consensus regarding the specific criteria, sub-criteria or their indicators in what concerns their inclusion in the assessment of transport infrastructure projects. According to Tsamboulas (2007), a maximum of 8 to 15 criteria should be included in the evaluation.

Barfod (2018) emphasized that the growing attention for sustainable development and environment in particular, has urged the consideration of the larger context when assessing transport projects, namely that the economic dimension should be evaluated concomitant with the environmental and social dimensions. As it is an even more growing interest in the environmental impact of transport infrastructure projects (and not only) as the new European Green Deal is placed at the center of all the nowadays policies development, we believe that the environmental criteria used in the MCA will receive increased attention.

If we are to look at the definition of the environmental criteria and its indicators, according to OECD (2008), “environmental indicators are essential tools for tracking environmental progress, supporting policy evaluation and informing the public”. OECD defined a list of 10 (general) key environmental indicators: Climate change – CO2 and greenhouse gas emission intensities, Ozone layer - ozone depleting substances, Air quality – SOx and NOx emission intensities, Waste generation – municipal waste generation intensities, Freshwater quality – waste water treatment connection rates, Freshwater resources – intensity of use of water resources, Forest resources – intensity of use of forest resources, Fish resources – intensity of use of fish resources, Energy resources – intensity of energy use, Biodiversity – threatened species. The European Environment Agency is an EU agency providing support in the environmental policy making through information and assessments of environmental matters. It maintains a number of 122 indicators, out of which 8 belong to the transport topic, namely: Greenhouse gas emissions from transport in Europe, Greenhouse gas emissions intensity of fuels and biofuels for road transport in Europe, Average CO2 emissions from newly registered motor vehicles in Europe, Emissions of air pollutants from transport, Use of renewable energy for transport in Europe, New registration of electric vehicles in Europe, Landscape fragmentation pressure and trends in Europe, Exposure of Europe’s population to environmental noise (European Environment Agency, 2020; European Environment Agency Transport Indicators, n.d.).

In 2019, the European Green Deal strategy was launched, setting out an ambitious plan for addressing climate and environmental-related challenges. Composed out of a set of policy objectives, its ultimate goal is to achieve a climate neutral Europe by 2050 (European Commission, 2019a). As the focus is on more environmental-friendly solutions, we could state that the environmental dimension received even a greater interest. In line with this developments, the environmental criteria employed in the assessment of transport infrastructure projects will have an increased variability in terms of its indicators, ranging from the ones related to resources (air and carbon emissions, water, soil) and their efficient and sustainable consumption (circular economy) towards the climate change measurements.

The purpose of this literature review article is to identify the specific multi-criteria decision-making techniques/methods and criteria employed in the context of transport infrastructure projects, as well as the indicators of the environmental criteria. Therefore, we have formulated the following research questions:

1. Which are the representative multi-criteria decision-making techniques/methods used for the transport infrastructure projects?

2. Which are the popular criteria used in the multi-criteria decision-making in the context of transport infrastructure projects?

3. What are the indicators of the environmental criteria?

This is a comprehensive, but not necessarily an exhaustive study and there is no doubt that there are some other articles or databases in which papers related to our purpose could be found. The results of this study are based on the methodology described in the following section. The reminder of this paper is as follows: the literature survey methods, the main findings of our research, results and conclusions and discussion.

2. LITERATURE SURVEY METHODS

For the purpose of this article, we focused specifically on the identification of transport infrastructure related articles and not on general transport-related subjects. The queries for relevant articles were performed in May 2020, using specific keywords in the search engine of two scientific databases, namely Web of Science and Science Direct (see Table 1). Web of Science is a highly acclaimed, comprehensive, scientific database, with about 171 million records, allowing for an extensive inquiry of the literature (Web of Science, n.d.). Moreover, we complemented the findings in Web of Science database with the ones from Science Direct, another well-known scientific database, owned by publisher Elsevier, in order to find any other additional article fitting our purpose, thus allowing for a more in-depth literature analysis. For the performed searches, the conditions required the keywords to be present in the title and/or in the title, abstract or keywords (defined as TOPIC in Web of Science). The common element of the searches was the method, meaning that we combined the keywords corresponding to the “method” column with the ones belonging to the “field” and afterwards with the “type of infrastructure” (the 5 transport modes), in order to find the articles tackling the transport infrastructure projects AND the multi-criteria decision-making. We noticed that in many articles “transport” and “transportation” are both used to refer to transport infrastructure. Moreover, we noticed a variety of forms/synonyms used to refer to the generic multi-criteria decision-making, including abbreviations as well, thus the multiple keywords referring to the method. We set some constraints, namely we were interested in the journal articles or conference proceedings being published between the years 2000 and 2020.

TABLE 1. KEY SEARCH TERMS

Keywords		
Method	**Field**	**Type of infrastructure**
Multi-criteria decision-making	Transport infrastructure	Railway infrastructure
Multicriteria decision-making	Transportation infrastructure	Road infrastructure
MCDM		Port infrastructure
Multi-criteria decision analysis		Airport infrastructure
Multicriteria decision analysis		Intermodal infrastructure
MCDA		
Multi-criteria analysis		
Multicriteria analysis		
MCA		

Source: realised by the authors

3. MAIN FINDINGS OF THE RESEARCH

The search results were analyzed in a structured way. First, in the pre-selection phase, we were screening if the selected articles are in English, then we selected the articles which were fully available, meaning that if only the abstract could be found, the article was not included in the review. Last, but not least, the abstracts were checked to be sure that the article was touching upon the two subjects, namely multi-criteria decision-making and transport infrastructure. As it can be seen in the Table 2, 63 articles were selected at the beginning for further analysis.

TABLE 2. OVERVIEW OF THE SEARCH RESULTS

Databases	Results		
	Number of individual retuned articles/database	Duplicates	Selected articles based on availability and the relevance of the abstract
Web of Science	182	48	60
Science Direct	61		3
TOTAL			**63**

Source: realised by the authors

4. RESULTS

Initially, the 63 selected articles were categorized based on their objective, resulting in 2 groups: review (either literature reviews, inventory and/or classification articles) and research papers. A number of 14 articles belong to the review category. We notice that in 3 articles (Nguyen et al., 2017; Olesen & Barfod, 2018; Broniewicz & Ogrodnik, 2020), aside from the literature review/inventory, case studies or new frameworks were also presented, therefore these articles were included in the category of research papers as well (summing up to 52 articles).

4.1. Previous review work

We further divided the 14 selected papers being considered as reviews into 3 groups: Inventory and/or classification papers (5 papers), Literature review papers (7) and Papers focusing on the review of decision-making methods related to mega transport projects (2). A summary of the findings from these review articles is given in the Table 3.

TABLE 3. SUMMARY OF THE REVIEW PAPERS

No.	**Reference**	**Formulated Research Questions**	**Method(s)**	**Criteria /Factors/Impacts**	**Sub-criteria/Indicators/ Attributes/Effects**
Inventory and/or classification papers					
1	Penalver& Turro (2018)	x	x	Typologies of territorial redistribution effects	Yes, effects and their sub-categories are presented
2	Nguyen et al. (2017)	x	√	Costs and benefits divided into projects implementation and project operation	Yes, the decomposition of different costs
3	Bueno et al. (2015)	x	√	Yes, criteria related to the three dimensions of the sustainability framework	x

4	Griskeviciute-Geciene (2010)	x	√	Yes, but not resulting from a literature review, but from isolated cases or particular project examples	Yes, but not resulting from a literature review, but from isolated cases or particular project examples
5	Olesen & Barfod (2018)	x	√	Yes, a comprehensive list of impacts to be considered in the assessment process is presented	Yes, a comprehensive list of impacts (and their definition) to be considered in the assessment process is presented
Literature review papers					
6	Macharis& Bernardini (2015)	√	√	x	x
7	Deluka-Tibljas et al. (2013)	x	√	Some criteria are mentioned in the text of the article, but not presented in a structured format, as their identification was not within the purpose of the article	Some sub-criteria are mentioned in the text of the article, but not presented in a structured format, as their identification was not within the purpose of the article
8	Mardani et al. (2015)	x	√	Some criteria are mentioned in the text, in the "results and outcome section"	x
9	Kabir et al. (2014)	x	√	x	x
10	Stojcic et al. (2019)	x	√	x	x
11	Thomopoulos et al. (2009)	x	√	x	Types of equity and principles
12	Broniewicz & Ogrodnik (2020)	x	√	x	x
Review of decision-making methods related to mega transport projects papers					
13	Dimitriou et al. (2016)	x	√	Yes, four project dimensions of sustainable development are presented	Yes, the components of the four project dimensions of sustainable development are presented
14	Ward et al. (2016a)	x	√	x	x

Source: realised by the authors based on the analyzed papers

In the first sub-category, the papers addressed inventories of methods, tools and frameworks used for the (sustainable) evaluation of (urban) transport infrastructure projects, as well as the classification of the different impacts of major transport infrastructure projects (redistribution effects), including territorial, social, environmental and intergenerational impacts, that should be taken into account when evaluating transport infrastructure projects (Griskeviciute-Geciene, 2010; Bueno et al., 2015; Nguyen et al., 2017; Olesen & Barfod, 2018; Penalver&Turro, 2018).

Regarding the papers sub-classified as literature review articles, their focus was mainly on the application of MCDM methods/techniques for different transport-related areas, such as: transport projects appraisal (Thomopoulos et al., 2009; Macharis&Bernardini, 2015), transport infrastructure in urban areas (Deluka-Tibljas et al., 2013), transportation and transportation systems (Mardani et al., 2015; Broniewicz & Ogrodnik, 2020), infrastructure management (Kabir et al., 2014), transportation or in a more general approach - sustainable engineering (Stojcic et al., 2019). As it can be seen, there are several articles in which the transport infrastructure was part of the purpose of the study, but not the main focus.

The last 2 papers, included under the reviewed-transport related issue regarding the decision-making methods related to mega transport projects sub-category, are based on the review, analysis and lessons learned from the investigations carried out by the OMEGA Research Centre (Dimitriou et al., 2016; Ward et al., 2016a).

The 14 selected articles were published between 2009 and 2020. In 2015, 2016 and 2018 there were more than 1 review article published, 3, 2 and 2 respectively (Bueno et al., 2015; Macharis&Bernardini, 2015; Mardani et al., 2015; Dimitriou et al., 2016; Ward et al., 2016a; Olesen & Barfod, 2018; Penalver&Turro, 2018). Among the selected papers, no review articles were published in 2011 and 2012.

In what concerns the research questions, none of the analyzed research papers have formulated the research questions distinctly, but one: Macharis&Bernardini (2015).

In all of the articles, except for Penalver&Turro (2018), the identification of decision-making methods (be it CBA, MCA/MCDM, PLMCA, MAMCA) applied in the transport infrastructure context is of interest. While it is mentioned that CBA received numerous critiques (Thomopoulos et al., 2009; Bueno et al., 2015; Dimitriou et al., 2016; Ward et al., 2016a; Nguyen et al., 2017; Penalver&Turro, 2018), the most used MCDM method was by far AHP; Fuzzy AHP and SAW were also mentioned as being frequently used (Deluka-Tibljas et al, 2013; Kabir et al, 2014; Macharis&Bernardini, 2015; Mardani et al., 2015) and the mix of multiple MCA or of MCA and GIS were often employed (Deluka-Tibljas et al., 2013). Stojcic et al. (2019) concluded that the existing MCDM models will continue to be used, while new/upgraded ones will emerge, including hybrid models, which can take into account the uncertainty.

Less than half of the review papers (6/14) did not make any inventory or presented any criteria (also referred to as factors, dimensions, effects or impacts) and/or sub-criteria (also referred to as indicators, attributes or elements) (Kabir et al. 2014; Macharis&Bernardini, 2015; Ward et al., 2016a; Stojcic et al., 2019; Broniewicz & Ogrodnik, 2020). As for the other review papers, the majority presented the criteria related to the transport infrastructure projects within the sustainability/sustainable development framework (Thomopoulos et al., 2009; Griskeviciute-Geciene, 2010; Deluka-Tibljas et al., 2013; Bueno et al., 2015; Dimitriou et al., 2016; Olesen & Barfod, 2018; Penalver&Turro, 2018) and/or according to the project life-cycle stages (Deluka-Tibljas et al, 2013; Nguyen et al., 2017).

The social, environmental and economic criteria (the three pillars of sustainability) are presented in most of the papers. In their article, Dimitriou et al. (2016) presents the four project dimensions of sustainable development: social, environmental, economic and institutional, as well as their respective components/sub-criteria, while Deluka-Tibljas et al. (2013), performing a review related to urban transport infrastructure, observed that the social, economic, environmental and traffic criteria, as well as their combination, are commonly used. In the latter article, there is also an explanation regarding maybe the low availability of criteria/sub-criteria inventory, namely that the choice of sub-criteria and their weights is context-dependent (both in terms of the type of problem and its constraints), leading to more rather general recommendation on the sub-criteria to be included in the decision-making process (Deluka-Tibljas et al., 2013).

Mardani et al. (2015), studying the application of MCDM methods in transportation systems, observed the criteria of safety, mobility and access, and local development as being mostly used.

As transport infrastructure projects are characterized by different impacts (also known as redistribution effects) following their implementation, Penalver&Turro (2018) concluded that these impacts are scarcely take-up into the decision-making models for major infrastructure investments, alongside with the economic, social and financial criteria. Penalver&Turro (2018) identified three levels of redistribution effects: (i) internal to the project (usually included in the CBA), (ii) effects usually not included in the CBA since they are difficult to be monetized

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(e.g. equity, social, environmental and territorial effects) and (iii) effects on climate change, as well as intergenerational redistributive effects, which hasn't received much attention. In the context of presenting a new transport projects assessment framework, Olesen & Barfod (2018) made a comprehensive list of impacts to be considered in the assessment process, divided in categories such as landscape, soil, nature, material assets and archaeological heritage, air pollution and climate, water and population, following an inventory of the 10 most recent EIA reports concerning road, rail and public transport projects in Denmark.

Alongside to the intergenerational redistributive effects, happening as the generations changed from the moment the infrastructure projects are implemented and until the initial investment is paid back (creating an uneven advantage among generations), the criteria of equity appeared to be of importance to be included in the evaluation of transport infrastructure projects (Thomopoulos et al., 2009; Penalver&Turro, 2018). In effect, Mardani et al. (2015) and Dimitriou et al. (2016) highlighted the limited consideration of equity, uncertainties, risks, the particular context, complexities in the evaluation methods for (mega) transport infrastructure projects. The integration of these criteria could offer a broader perspective on the implementation of transport infrastructure projects, over and above the usual specific indicators of the iron triangle (Dimitriou et al., 2016).

Focusing on reviewing the assessment tools of sustainability applied to transport infrastructure projects, Bueno et al. (2015) presented the criteria related to the three dimensions (economic, social and environment) of the sustainability framework for highway projects, throughout their life cycle. Taking into account the stages of life-cycle/development cycle of the transport infrastructure projects is an idea supported by Deluka-Tibljas et al. (2013), Dimitriou et al. (2016) and Nguyen et al. (2017), as well. Nguyen et al. (2017) devided the criteria presented for a "hybrid" CBA approach as belonging to the project implementation phase and project operation phase and Deluka-Tibljas et al. (2013) underlined the fact that MCA is not extensively used in design, reconstruction or maintenance phase of transport infrastructure, as it is the case for the planning phase of transport infrastructure planning in urban areas. Actually, according to Deluka-Tibljas et al. (2013), no article was focusing on the application of MCA in the preparation phase of the transport infrastructure construction.

Another important analyzed aspect is the involvement of the stakeholders in the decision-making process, which seems to be an issue (Thomopoulos et al., 2009; Kabir et al, 2014; Macharis&Bernardini, 2015).

In a nutshell, the main finding from studying these review articles is that although the focus of most of the papers is on analyzing the applications of the MCDM in the field of transport, few of them are dedicated solely to transport infrastructure projects and towards making an inventory regarding the employed criteria or sub-criteria.

4.2. Classifications and observation

In this section, we describe the results of the analysis of the 52 articles, 49 categorized as "research papers" and 3 derived from the review articles pool, as having a second purpose, as well, namely to present case studies or (new, improved) frameworks. Here, we started the analysis by an in-depth studying of the selected articles, which represented another filter for the refinement of the included articles. 4 more articles, which initially fulfilled the selection criteria, were removed as they were focusing on the transport infrastructure in general (and not a specific mode of transport) (Miceviciene et al., 2009; Ward et al., 2019), on determining the urban public transport infrastructure criteria with the most influence on passengers' satisfaction (Uspalyte-Vitkuniene et al., 2020) or it was an in-progress article and the results were not yet available (Caetano et al., 2018). Therefore, a total of 48 articles remained for the study.

4.2.1. 4.2.1. An overview

In this section, we analyzed the selected papers based on the publication year, publication journal, type of paper (journal/conference proceedings), and keywords.

The frequency distribution by publication year is shown in Figure 1. We focused on the papers published between 2000 and 2020. No article included in this analysis was published before 2007 and neither in 2008. We noticed a peak in 2018, when the highest number of articles were published, namely 13, with the second highest number in 2012 and 2017 (6 articles). However, one must interpret this result with care, as this is the result of our own search strategy.

Out of the total 48 selected articles, 32 were journal articles, while 16 were conference proceedings. Table 4 displays the top of the journals and conferences proceedings in which the selected papers were published. In terms of number of articles, Procedia – Social and Behavioral Sciences and Transport Policy rank the firsts (with 4 papers each), followed by European Transport Research Review, International Conference on Road and Rail Infrastructure and Transportation Research Part D: Transport and Environment, ranked on the second position, with 3 articles each. The third position is occupied by Journal of Advanced Transportation, Research in Transportation Economics, Sustainability, Transport, Transportation Research Part A: Policy and Practice and Transportation Research Procedia (2 papers, each).

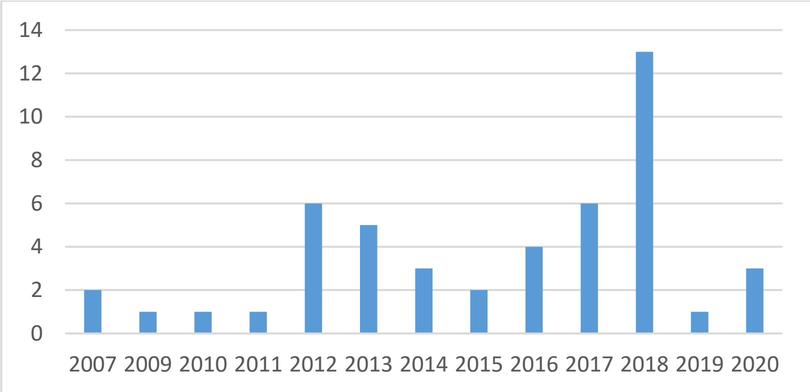

FIGURE 1. PAPERS ADDRESSING THE APPLICATION OF MCA FOR TRANSPORT INFRASTRUCTURE PROJECTS PUBLISHED BETWEEN 2000 AND 2020

Source: realised by the authors based on the analyzed papers

In what concerns the keywords, 5 articles did not have any keywords (Montmain et al., 2009; Beukes et al., 2013; Cornet et al., 2018; Couto et al., 2018; Farooq et al., 2018). There was a total number of 215 keywords, out of which the most frequent was "Multicriteria analysis" (12 times), followed by "Cost-benefit analysis" (7 times) and "Decision Support System", "Multi-criteria decision analysis", "Sustainability" and "Transportation" (4 times, each of them). "AHP", "Decision Making" and "Transport infrastructure" were on the fourth position, with a frequency of 3 times each. Further, we grouped them into five categories, although the delimitation among them is not clear-cut, as some of the keywords can be included in more categories:

a) Decision-making: various types of decision-making techniques/analyses/approaches including, among others MCA (with its variations – e.g. MCDM, multi-criteria analysis), specific MCA (AHP, TOPSIS, etc.), CBA, LCA, or even some particular ones, such as SUMINI (SUstainable Mobility INequality Indicator). This category counts for the most numerous keywords, namely 105.

b) Transport infrastructure management: this category is related to the previous one, as the decision-making techniques are applied in the management of transport infrastructure project (prioritization, evaluation, appraisal, etc.). This category has 66 keywords.

c) Transport infrastructure: various keywords related to transport modes or transport infrastructure projects (renewal & improvement), with 50 keywords.

d) Sustainability: as the development of transport infrastructure projects are taking place under the sustainability paradigm, this category ranks as fourth, with 28 keywords.

e) Others: this category includes the keywords that did not fit into the ones above, for example location (France, Brundtland) or uncertainty, with a total of 8 keywords.

TABLE 4. JOURNALS AND CONFERENCES PUBLISHING ARTICLES RELATED TO THE APPLICATION OF MCA IN TRANSPORT INFRASTRUCTURE PROJECTS IN 2000-2020

Journal/Conference	Number of papers
Procedia - Social and Behavioral Sciences	4
Transport Policy	4
European Transport Research Review	3
International Conference on Road and Rail Infrastructure	3
Transportation Research Part D: Transport and Environment	3
Journal of Advanced Transportation	2
Research in Transportation Economics	2
Sustainability	2
Transport	2
Transportation Research Part A: Policy and Practice	2
Transportation Research Procedia	2
Advanced Engineering Informatics	1
Cities	1
Computer-Aided Civil and Infrastructure Engineering	1
Decision Support Systems	1
Environmental Impact Assessment Review	1
Environmental Modelling & Software	1
International Conference Environmental Engineering (ICEE)	1
International Conference on System Science and Engineering (JCSSE)	1
International Conference on Traffic and Transport Engineering (ICTTE)	1
International Journal of Environmental Research and Public Health	1
International Journal of Sustainable Development & World Ecology	1
IOP Conference Series: Materials Science and Engineering	1
Journal of Cleaner Production	1
MATEC Web of Conferences - 14th International Conference on Vibration Engineering and Technology of Machinery (VETOMAC)	1
Structure and Infrastructure Engineering	1
The 2nd Asian Simulation Technology Conference, ASTEC'2010 : Complex Systems Simulation and Transport Simulation	1
Transportation	1
Transylvanian Review of Administrative Sciences	1
Urban Transport	1

Source: realised by the authors based on the analyzed papers

4.2.2. 4.2.2. MCDM used

In what concerns the MCDM used, the most used one is AHP, followed by Weighted MCA methods and TOPSIS, as it can be seen in the chart below. We were also interested in finding out how these MCA methods were employed individually, in combination among them, or even in combination with other decision-making methods (CBA, GIS, LCA etc).

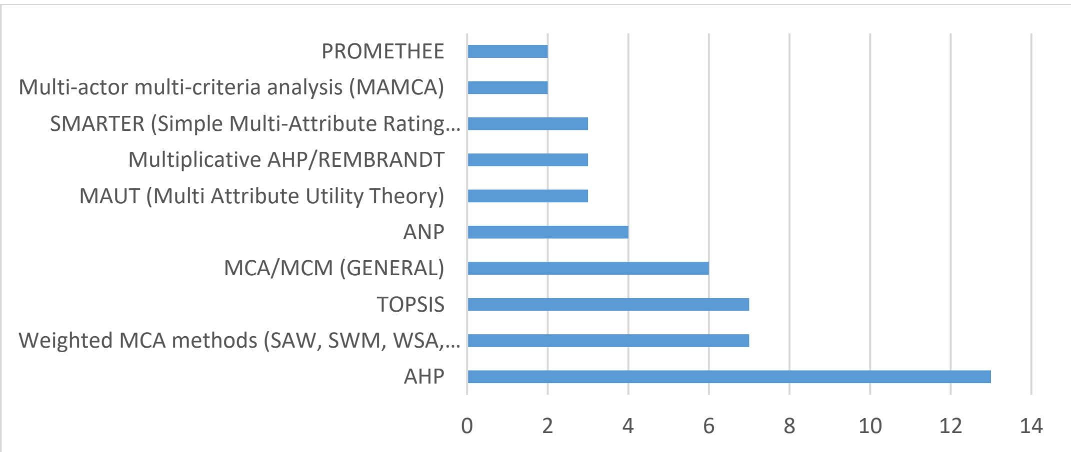

FIGURE 2. THE FREQUENCY OF MCA METHODS APPLIED IN ASSOCIATION WITH TRANSPORT INFRASTRUCTURE PROJECTS DECISION-MAKING ISSUES

Source: realised by the authors based on the analyzed papers

We discovered that in 12 articles a single MCA method was employed, while a combination of techniques, was applied in 28 articles (e.g. in Barfod & Sailing, 2015; Karlson et al., 2016; Nguyen et al. 2017; Vulevic et al., 2018). Multiple MCA methods were presented in 7 articles, for example to present the evaluation outcomes of road infrastructure project alternatives when employing multiple MCA - as in Glavinov et al. (2012), while in only one article a general MCA method was used (Couto et al., 2018). Regarding the use of a combination of MCA and other decision-making methods, new-named decision-support models emerged, such as COSIMA (Ambrasaite et al., 2011), SUMINI (Thomopoulos & Grant-Muller, 2013), SINERGIE (Montmain et al., 2009) etc.

We also noticed an evolution of MCA methods frameworks in the sense that, it includes not only a large array of criteria, but also is taking into account multiple actors/stakeholders and their judgements: for example, the multi-actor multi-criteria analysis (MAMCA) as in Cornet et al. (2018) and Roukouni et al. (2018), group decision-making as in Belosevic et al. (2018) and Zak et al. (2014), or even a multi-actor, multi-level context (such as the Competence-based Multi-criteria Analysis (COMCA) in te Boveldt et al. (2018)). Ward et al. (2016b) presented a new approach in which “policy leadership can be introduced into MCA processes for the appraisal of large-scale infrastructure projects” (Ward et al., 2016a). Spatial Multi-Criteria Analysis (SMCA), the combination of GIS and MCA was applied in Beukes et al. (2013) and Karlson et al. (2016). This association, of GIS and MCA, was often discovered in the analyzed articles, although not under the SMCA name (see De Luca et al., 2012; Lambas et al., 2016; Al-yasery et al., 2018; Farooq et al., 2018; Vulevic et al., 2018).

The sustainability dimension, composed out of its three dimensions of economy, society and environment increased in its importance along the time, being integrated in the planning of transport infrastructure and contributing to the emergence of different assessment tools and techniques. As it promotes the sustainable outcomes over shorter-term gains, these methods stared to be integrated or employed next to well-known MCA methods. An example in this sense is the combination of MCA with Life Cycle Assessment (LCA) – a methodology assessing the environmental impacts in all the stages of the life-cycle of the (transport infrastructure) project, from construction to operation and dismantle, as seen in Yang et al. (2016) and Barrientos et al. (2016) or the development of integrated methods such as SUMINI (SUstainable Mobility INequality Indicator) based on composite indicators and AHP (Thomopoulos & Grant-Muller, 2013) or EnvFusion (Environmental Fusion for ITS) based on Lifecycle Inventory, Lifecycle Impact Assessmet (LCIA), AHP and Dempster-Shafer theory (Kolosz et al., 2013). Pryn et al. (2015) applied the sustainability advocate view, by asking a group of stakeholder to approach the standard pair-wise comparison of criteria from an explicit sustainability perspective. Other papers did not focus on employing an environmental assessment method next to the MCA, but included criteria belonging to the sustainability dimension (Guhnemann et al., 2012; Bryce et al., 2014; Barfod & Sailing, 2015; Nguyen et al., 2017; Sierra et al., 2017; te Boveldt et al., 2018).

Building on the limitations of each other, the MCA was often used in combination with CBA and, as part of the usual CBA approach – the risk analysis, with (feasibility) risk assessment and Monte Carlo simulation (Salling et al., 2004; Leleur et al., 2009; Ambrasaite et al., 2011; Guhnemann et al., 2012; Tsamboulas et al., 2013; Barfod & Sailing, 2015; Nguyen et al., 2017; Sierra et al., 2017; Tischler, 2017; Olesen & Barfod, 2018).

4.2.3. 4.2.3. Type of projects and analysis (ex-post/ex-ante)

Only in three articles an ex-post analysis (taking place after the implementation of a transport infrastructure project) was presented (Salling et al., 2004; Thomopoulos & Grant-Muller, 2013; Zembri-Mary, 2017). Although the assessment focused on existing (therefore, referring to upgrading, modernization, rehabilitation, improvement, renewal, replacement, (re)development projects) as well as new planned infrastructure projects, all the rest of the analysis methods were ex-ante, targeting the planning part of the transport infrastructure project, before the actual implementation of the project.

4.2.4. 4.2.4. Mode of transport

Regarding the transport mode, we grouped them into 7 categories: road, railway, intermodal, fixed link, port, urban (identified based on project location) and corridors, as it can be seen in Table 5. In two articles (Zembri-Mary, 2017; Farooq et al., 2018), two transport modes were presented (road and railway). In addition, Farooq et al. (2018) presented also the metro infrastructure as an alternative. In the highest number of articles, urban (14) and railway projects (12) were presented, followed by road (11), and fixed link projects (6). The latter is a type of project associated in the selected articles with the Nordic countries (Sweden, Denmark) and refers to (cross-border) tunnels or high-level bridges or road/rail connections across water (Salling et al., 2004; Leleur et al., 2009; Thomopoulos & Grant-Muller, 2013; Barfod & Sailing, 2015; Pryn et al., 2015; Barfod, 2018). The corridor category comprises of 3 articles and presents the cases of transport infrastructure projects assessment located on the Trans European Motorway and Railway networks (TEM/TER) corridor (Tsamboulas, 2007), and on a national (Danish) corridor (Olesen & Barfod, 2018) or the case of the Danube Corridor accessibility evaluation in Serbia (Vulevic et al., 2018).

TABLE 5. MODE OF TRANSPORT ADDRESSED IN THE ANALYZED PAPERS

No.	Mode	Articles (sources)
1	Road	Montmain et al., 2009; Glavinov et al., 2012; Guhnemann et al., 2012; Kolosz et al., 2013; Bryce et al., 2014; Nogues & Gonzalez-Gonzalez, 2014; Nguyen et al., 2017; Sierra et al., 2017; Zembri-Mary, 2017; Farooq et al., 2018; Broniewicz & Ogrodnik, 2020
2	Railway	Ambrasaite et al. 2011; De Luca et al., 2012; Longo et al., 2012; Macura et al., 2012; Barrientos et al., 2016; Montesinos-Valera et al., 2017; Tischler, 2017; Zembri-Mary, 2017; Belosevic et al., 2018; Cornet et al., 2018; Couto et al., 2018; Farooq et al., 2018
3	Intermodal	Martinov, 2018; Zgaljic et al., 2019; Lizbetin & Stopka, 2020
4	Fixed link	Salling et al., 2004; Leleur et al., 2009; Thomopoulos & Grant-Muller, 2013; Barfod & Sailing, 2015; Pryn et al., 2015; Barfod, 2018
5	Port	Libardo & Parolin (2012)
6	Urban	Shishegaran et al., 2009; Beukes et al., 2013; Ivanovic et al., 2013; Tsamboulas et al., 2013; Zak et al., 2014; Karlson et al., 2016; Lambas et al., 2016; Ward et al., 2016b; Yang et al., 2016; Jakimavicius et al., 2017; Al-yasery et al., 2018; Mansourianfar & Haghshenas, 2018; Roukouni et al., 2018; te Boveldt et al., 2018
7	Corridors	Tsamboulas, 2007; Olesen & Barfod, 2018; Vulevic et al., 2018

Source: realised by the authors based on the analyzed papers

4.2.5. 4.2.5. Criteria and sub-criteria

As the number of the criteria included in the models presented in the selected article was too high, the criteria were analyzed according to the mode of transport, and consequently, the sub-criteria as well (although the latter was found to be used in very few cases).

4.2.5.1. Urban transport infrastructure

The articles were categorized under this group based on the location of the projects presented. In this category of projects, we were not interested in the papers addressing solutions to traffic management, but rather on larger transport infrastructure projects. All the articles included in this category except for two (Jakimavicius et al., 2017; Al-yasery et al., 2018) have taken into account the environmental criteria (cluster) into account.

Focusing on the case of an inter-jurisdictional infrastructure planning, te Boveldt et al. (2018) presented a list with different criteria used by different actors, as their interest is not of a general nature, but rather variable. Focusing on the application of MCA for the evaluation of different value-capture financing (VCF) mechanisms for urban transport infrastructure, Roukouni et al. (2018) presented the same approach, namely using different criteria for different actors.

Innovation criteria appear in only two articles, but should be mentioned that those articles were focused mostly on financial mechanisms (VCF and public private partnership) (Tsamboulas et al., 2013; Roukouni et al., 2018).

Although there was some variation among the urban infrastructures presented (ranging from railway, to metro, light rail, bus rapid transit to (major) street (re)development), for the majority of the articles, the criteria can be clustered in the three sustainability pillars (economic, social and environment) and transportation. Of course the criteria included in each cluster varies from article to article. An extensive list of (possible) appraisal criteria, derived from the policies and their respective objectives, was provided by Ward et al. (2016b).

4.2.5.2. Railway

One of the first findings when looking into the used criteria among the papers in this category is the fact that in three articles, focusing on modernization/rehabilitation/improvement/renewal railway infrastructure projects, environmental criteria were not included, but rather more technical ones (Macura et al., 2012; Montesinos-Valera et al., 2017; Couto et al., 2018).

Ambrasaite et al. (2011) grouped the criteria used in their model into monetary (derived from the CBA results) and non-monetary. Macura et al. (2012) included the cost-benefit ratio as one of the criteria in their evaluation, as well. Another interesting clustering was presented in Cornet et al. (2018), who divided the criteria into direct project impacts (internal costs and benefits), indirect societal impacts (the so-called externalities, affecting the people) and environmental impacts (the externalities of the project affecting the planet).

Similar to the urban infrastructure context presented above, the criteria used in the majority of the papers addressing the railway infrastructure can be clustered into four categories: transportation, social, economic and environmental.

4.2.5.3. Road

Presenting the case of a „hybrid” approach (CBA combined with MCM), Guhnemann et al. (2012) classified the criteria into monetized impacts (extracted from the CBA) and non-monetized impacts, the latter which can be assessed either qualitatively (as is the case for biodiversity, water resources or cultural heritage) or quantitatively (as for accessibility, safety and integration).

Nguyen et al. (2017) divided the criteria in two clusters, according to the phase of the project: implementation-related criteria (direct and indirect costs, project benefits during implementation) and project operation-related (project benefits during operation, costs, customers/distributors/retailers, market price); for each criterion, indicators were established.

Kolosz et al. (2013) focused on how the deployments of ITS on highways can contribute to the sustainable and green transport goals. Although we mentioned earlier that we were not interested in traffic management solutions, we retained this article as it addressed the sustainability concept in the transport infrastructure project, with a focal objective on environmental impact. The criteria used for their model belong to four clusters: environmental, energy, social and economic. The energy consumption is a criterion which is part of the decision analysis technique, for sustainable infrastructure management, presented in Bryce et al. (2014), as well. Remarkably, the criteria were clustered according to the three sustainability pillars in none of the articles. However, this does not mean that the specific criteria were not employed. For example, the environmental criteria could be found in the majority of the articles, for example in Montmain et al. (2009), Glavinov et al. (2012), Guhnemann et al. (2012), Kolosz et al. (2013), Nogues & Gonzalez-Gonzalez (2014), Farooq et al. (2018) or in Broniewicz & Ogrodnik (2020). The social criteria cluster was also present in more papers (for example in Montmain et al., 2009; Broniewicz & Ogrodnik, 2020). Aside from the ITS-related criteria or the division according to project phase, some other particular criteria were: security, public image and regulation (Montmain et al. (2009)), participation (Sierra et al. (2017)), defence and system of civil protection (defined as linking the defence directions) (Glavinov et al. (2012)).

Sub-criteria were employed in only two articles belonging to road infrastructure related articles (Glavinov et al., 2012; Guhnemann et al., 2012).

4.2.5.4. Intermodal

None of articles included sub-criteria in the assessment model. One of the main observations regarding these articles is that the number of criteria employed increases as the assessment moves from a single intermodal terminal (Lizbetin & Stopka, 2020) towards a corridor approach assessment (terminals location on a railway network or the port system integration with other modes of transport, as in Martinov (2018) and Zgaljic et al. (2019), respectively). However, the criteria observed in the three articles can be grouped in the following categories: costs for developing the project (construction and operation), infrastructural criteria group (including the characteristics concerning all the envisioned mode of transport), the interaction with different transport modes (for example, as in Zgaljic et al. (2019), the number of Short Sea Shipping services, number of railway operators in the country or prioritization of the Motorways of the Sea services), and administrative-political criteria group.

4.2.5.5. Fixed link

Two out of six papers employed criteria belonging to the three pillars of sustainability: economic, social and environmental (Pryn et al., 2015; Barfod, 2018). Although the categories were the same, the definition of specific indicators defined in each of the category is different, when analyzing the 2 papers. Other two papers present similarities: the combination of Feasibility Risk assessment and MCA is used in both of them and among the criteria employed the impact on towns and the impact on regional economies are common (Leleur et al., 2009; Barfod & Sailing, 2015). The other criteria are impact on flexibility in logistics, on ecology or on transport network and accessibility, the socio-economic robustness or the Robustness of feasibility, the improvement for passenger cars and public transport, the contribution to the EU green corridors (Leleur et al., 2009; Barfod & Sailing, 2015).

Focusing on a wider set of impacts in the assessment of transport infrastructure projects, a particular category of criteria is presented in Thomopoulos & Grant-Muller (2013), related to equity types: horizontal, vertical, environmental, regional and accessibility.

No sub-criteria were presented in these articles.

4.2.5.6. Port

There was only one article focusing on port development (Libardo & Parolin, 2012). One particular cluster of criteria when compared to other modes of transport is the "Risk Indicator" cluster, composed out of: potential loss of life, dangerous goods, bunker spill, damage on the fleet coming in the port, per year, and cargo loss or damage criteria. The other criteria categories were the environmental impact, transport performance, economic sustainability (referring to the time and costs for the completion of the project) and economic benefit.

No sub-criteria were presented.

4.2.5.7. Corridors

The criteria presented in the articles were categorized under clusters, ranging from particular ones (such as accessibility by road, as in Vulevic et al., 2018) to more general ones, such as socio-economic (Tsamboulas, 2007) or monetary and non-monetary clusters (Olesen & Barfod, 2018). Aside from the most common criteria used in the evaluation of transport infrastructure projects, for corridor projects we found out that the accessibility criteria clusters (defined in terms of technical indicators such as, among others, length of the network and density) (Vulevic et al., 2018) or the cross-border focus of the criteria seen in the “functionality and coherency of the transport network” cluster or the “strategic/ political concerns of national and international authorities involved” category (Tsamboulas, 2007), are more specific. In addition, as the focus of Tsamboulas (2007) was the prioritization of the multinational transport infrastructure investments, one noteworthy criterion from the socio-economic return on investment cluster was the financing feasibility.

A particular feature of the article of Olesen & Barfod (2018) is the fact that in deploying AHP, they included not only sub-criteria, but also sub-sub-criteria. Although it was a simulation, without actually asking the specific groups of stakeholders to give weights to the criteria, the article presents the comparative weighting obtained from three different profiles: local, political and sustainability perspectives.

4.2.6. 4.2.6. The environmental criteria

Only 9 out of the 48 studied articles (about 18%) did not employed environmental criteria in the analysis (Macura et al., 2012; Jakimavicius et al., 2017; Montesinos-Valera et al., 2017; Al-yasery et al., 2018; Couto et al., 2018; Martinov, 2018; Vulevic et al., 2018; Zgaljic et al., 2019; Lizbetin & Stopka, 2020). We divided the environmental criteria into 9 groups: Resources, Efficiency of consumption and material footprint, Noise & vibrations, Climate change, General, Traffic-related, Safety, Smart, green and sustainable city and Other. The resources group was further decomposed in sub-groups: Air, Water, Soil, Land-use and heritage, and Biodiversity, nature and ecology. Not surprisingly, the majority of indicators could be grouped under the Resources category, which is in line with the environmental protection advocated through the sustainability policies. An overview of the indicators could be seen in Table 6.

Although OECD (2008) included under the Climate change criteria the CO2 and greenhouse gas emission intensities indicators, starting from the definition of climate change – “a significant change in the measures of climate, such as temperature, rainfall, or wind, lasting for an extended period – decades or longer” (Environmental Protection Agency of Ireland, n.d.), we advocate that climate change dimension should focus on the measurements of temperature and effects determined by the increasing temperature and measures to mitigate these effects. Therefore, in our study, only the indicator presented in Ward et al. (2016b), namely Adequacy of flood protection measures, was included.

In the “other” category we included the indicators related to the ITS system presented in Kolosz et al. (2013) (Scheme Lifecycle Emissions, Road User Emissions, KG of GWP covered by IT certificates, KG of GWP per IT task or resource), as well as Agriculture & Forestry or Artificial/Agricultural land and the Construction technological immaturity.

Regarding the noise pollution, we noticed that Shishegaran et al. (2009) associated this indicator with the social dimension, illustrating that there is not a clear cut line between the indicators which can be included under a category or another.

TABEL 6. THE ENVIRONMENTAL CRITERIA INDICATORS

Group	Sub-group	Indicators	Sources
Resources	Air	Pollution, Air pollution, Local pollution, Emission cost, Emissions, Evidence that proposals are likely to enable the achievement of the highest possible environmental standards with regard to air, noise and water quality, Air Pollution NOx, Air Pollution PM10, Air Pollution CO, Air quality, Air & Climate, Construction noise and air pollution (CAN), Air pollution (CO, HC and NOx emission), Air pollution (NOx, HC and CO emission per hour), GHG emission (CO2 emissions per hour), Length of sections with high pollution risk, Air pollution and climate, Variation in CO2 emissions (% or #), Air Pollution CO2, Carbon footprint, Global emissions (CO2)	Salling et al., 2004; Shishegaran et al., 2009; Libardo & Parolin; 2012; Thomopoulos & Grant-Muller, 2013; Pryn et al., 2015; Lambas et al., 2016; Ward et al., 2016b; Yang et al., 2016; Nguyen et al., 2017; Tischler, 2017; Barfod, 2018; Cornet et al., 2018; Mansourianfar & Haghshenas, 2018; Olesen & Barfod, 2018; Broniewicz & Ogrodnik, 2020
	Water	Evidence that proposals are likely to enable the achievement of the highest possible environmental standards with regard to air, noise and water quality, Water & land contamination, Water	De Luca et al., 2012; Beukes et al., 2013; Thomopoulos & Grant-Muller, 2013; Ward et al., 2016b; Tischler, 2017;

		resources & flood risks, Water, Interference with a stream (course of water), Hydraulic risk, Water crossings, Proximity to wetlands	Cornet et al., 2018; Olesen & Barfod, 2018
	Soil	Geological suitability for construction, Geological suitability for aggregate, Slope, Soil thickness, Agriculture, forestry & soils, Water & land contamination, Landslide risk, Seismic risk and Volcanic risk, Geolithologic Composition, Intersection length of soil complex, Soil	De Luca et al., 2012; Karlson et al., 2016; Cornet et al., 2018; Olesen & Barfod, 2018; Broniewicz & Ogrodnik, 2020
	Land-use and heritage	Impact on towns and land-use, Impact on towns, Evidence of impact on historic sites and resources resulting from proposals, Spatial development, Land use, Landscape, General Interference, Specific Interference with roads, Specific interference with urban areas, Characteristics of the areas crossed (urban, agricultural, etc.), Fragmentation, Effect on landscape, Land consumption and Green spaces destruction, Physical impact on the coast, Historical patrimony, Land use, Number of collisions with cultural heritage objects, number of demolitions of residential buildings, Proximity to heritage sites, material assets and archaeological heritage	Leleur et al., 2009; Ambrasaite et al., 2011; De Luca et al., 2012; Libardo & Parolin, 2012; Longo et al., 2012; Beukes et al., 2013; Thomopoulos & Grant-Muller, 2013; Barfod & Sailing, 2015; Lambas et al., 2016; Ward et al., 2016b; Tischler, 2017; Mansourianfar & Haghshenas, 2018; Olesen & Barfod, 2018
	Biodiversity, nature and ecology	Local biodiversity impacts, Valuable areas - Ecological profile, Movement pathways, Stepping stones, Biodiversity & nature, Solid waste & disposal, Ecosystems, Percentage of internal park area (area of high environmental value), Zoning of Park, Visual impact, Landscape values, Degree of naturalness, Degree of biodiversity, Ecological damage (ED), Proximity to protected areas, Natural habitat intersection, Impact on ecology, Impact on fjord, Natural environment, The occupied area of Natura 2000 sites in the investment's demarcation lines, The length of the investment's Natura 2000 sites intersections, The number of vascular plant species destroyed, The number of species of fungi (lichen) destroyed , Area of destroyed natural habitats from Annex I to the Habitats Directive, Impact on snail habitats, Impact on insect habitats, The number of herpetofauna sites in the test buffer, Proximity to ecologically sensitive areas, Nature	Leleur et al., 2009; De Luca et al., 2012; Longo et al., 2012; Beukes et al., 2013; Thomopoulos & Grant-Muller, 2013; Pryn et al., 2015; Karlson et al., 2016; Yang et al., 2016; Tischler, 2017; Barfod, 2018; Cornet et al., 2018; Olesen & Barfod, 2018; Broniewicz & Ogrodnik, 2020
Efficiency of consumption and material footprint		Fuel consumption savings, Fuel consumption, Energy, Energy consumption, Energy saving, Material	Shishegaran et al., 2009; Libardo & Parolin, 2012; Kolosz et al., 2013; Bryce et al., 2014;

		footprint, Energy used per task or resource, Annual DCIE/PUE for DC, Roadside Energy Consumption, Consumption of natural resources (Fuel consumption and Green spaces destruction and Land consumed for transport)	Nguyen et al., 2017; Cornet et al., 2018; Mansourianfar & Haghshenas, 2018
Noise &vibration		Evidence that proposals are likely to enable the achievement of the highest possible environmental standards with regard to air, noise and water quality, Noise level, Noise, Noise & vibration, Health & well-being, Construction noise and air pollution (CAN), Noise annoyance, Number of buildings exposed to excessive noise	Thomopoulos & Grant-Muller, 2013; Ward et al., 2016b; Yang et al., 2016; Tischler, 2017; Barfod, 2018; Cornet et al., 2018; Broniewicz & Ogrodnik, 2020
Climate change		Adequacy of flood protection measures	Ward et al., 2016b
General		Contribution to the EU green corridors, Global environmental impact, Local environmental impact, Environmental and historical/heritage issue, Environmental - -Linking the populated places, Environmental friendliness, Environmentally friendly transport, Environmental impacts, Environment, Environmental assessment, Environmental and safety impacts	Tsamboulas, 2007; Montmain et al., 2009; Glavinov et al., 2012; Ivanovic et al., 2013; Tsamboulas et al., 2013; Nogues & Gonzalez-Gonzalez, 2014; Zak et al., 2014; Barfod & Sailing, 2015; Ward et al., 2016b; Zembri-Mary, 2017; Belosevic et al., 2018; Farooq et al., 2018; te Boveldt et al., 2018
Traffic		Trips generated, Traffic flow - Traffic intensity	Glavinov et al., 2012; Ward et al., 2016b
Safety	Safety during construction	Months construction of the project, fewer than 24, Mean annual daily traffic interval, The work requires direct access to the main road, Preexistence of social problems in the context	Sierra et al., 2017
	Safety in operations	Verification of applicable design conditions, Danger of the context, Environmental and safety impacts	Tsamboulas et al., 2013; Sierra et al., 2017
Smart, green and sustainable city		Smart and green city, Sustainable city	Roukouni et al., 2018
Other		Agriculture & Forestry, Construction technological immaturity (CTI), Artificial/Agricultural land, Scheme Lifecycle Emissions, Road User Emissions, KG of GWP covered by IT certificates, KG of GWP per IT task or resource	Kolosz et al., 2013; Thomopoulos & Grant-Muller, 2013; Yang et al., 2016; Tischler, 2017

Source: realised by the authors based on the analyzed papers

5. CONCLUSIONS AND DISCUSSION

The scope of this paper is to review the available literature for identifying the specific multi-criteria decision-making techniques/methods and the criteria employed in the context of transport infrastructure projects. Moreover, we were interested in assessing the environmental criteria and its indicators. Therefore, we performed a literature review, analyzing the papers, published between 2000 and 2020, retrieved from Web of Science and Science Direct, using specific keywords in their search engine. To guide our research, we addressed 3 research questions: "Which are the representative multi-criteria decision-making techniques/methods used for the transport infrastructure projects?", "Which are the popular criteria used in the multi-criteria decision-making in the context of transport infrastructure projects?" and "What are the indicators of the environmental criteria?".

The results of this analysis show that the number of articles addressing the transport infrastructure assessment specifically (and not transport, in its broader sense) is limited, a finding which is in line with the results of other literature review articles. Initially, we selected 63 articles, which is a smaller number when compared with other literature review papers (for example, 276 articles in Macharis&Bernardini, (2015), with only 11% related to infrastructure or 300, out of which only 56 articles in transportation infrastructure category, in Kabir et al. (2014)), but this result should be interpreted in conjunction with the specific purpose of this study, namely the focus on transport infrastructure. Worth mentioning is that we found three review papers focused on transport infrastructure, but one was limited to urban infrastructure (Deluka-Tibljas et al., 2013) and two which included also categories such as public transport, container lines or public logistic centers (Mardani et al., 2015; Broniewicz & Ogrodnik, 2020). Therefore, our approach seems to be particular, as we grouped the selected articles into 7 categories: road, railway, intermodal, fixed link, port, urban (identified based on project location) and corridors. In the highest number of articles, urban (14) and railway projects (12) were presented. Road infrastructure-related and fixed-link projects came next, with 11 and 6 articles.

We categorized the papers in literature reviews (in a broader sense, leading to 14 articles) and research papers (48 papers), for which a more in-depth analysis was carried out. Although we were interested in the articles published between 2000 and 2020, we did not have in our analysis any article published before 2007 and neither in 2008. Our analysis show that the highest number of published articles was in 2018 (13 articles), with the second highest number in 2012 and 2017 (6 articles).

Out of the total 48 research articles, 32 were journal articles and 16 - conference proceedings, the most numerous being publish in Procedia – Social and Behavioral Sciences and Transport Policy rank the firsts (with 4 papers each), followed by European Transport Research Review, International Conference on Road and Rail Infrastructure and Transportation Research Part D: Transport and Environment (3 articles each) and by Journal of Advanced Transportation, Research in Transportation Economics, Sustainability, Transport, Transportation Research Part A: Policy and Practice and Transportation Research Procedia (2 papers, each).

In what concerns the keywords, the most popular ones are related to decision-making methods: "Multicriteria analysis" (12 times), "Cost-benefit analysis" (7 times) and "Decision Support System", "Multi-criteria decision analysis", followed by "Sustainability" and "Transportation" (4 times, each of them). We also grouped the keywords in five categories: decision-making, transport infrastructure management, transport infrastructure, sustainability and others.

5.1. Multi-criteria decision-making methods/techniques

Consistent with the findings of other literature review (e.g. Deluka-Tibljas et al., 2013; Kabir et al., 2014; Macharis&Bernardini, 2015; Broniewicz & Ogrodnik, 2020), we discovered that AHP is the most commonly used MCA method. Mardani et al. (2015) included as the most popular identified methods AHP and Fuzzy AHP. The fuzzy and hybrid MCA methods are also noticed to be evolving, according to Broniewicz & Ogrodnik (2020).

In what concerns the fuzzy MCA methods, these were employed in only two analyzed articles Belosevic et al. (2018) and Broniewicz & Ogrodnik (2020); fuzzy VIKOR, applied for the ranking of project alternatives in the early stages of the project development, characterized by the existence of the uncertainties, and fuzzy AHP were used. In Broniewicz & Ogrodnik (2020), the classical and fuzzy set theories were used to estimate the criteria weights in the assessment of the layout of a planned road infrastructure. Although in other literature review an ascending trend in the use of fuzzy MCA methods was observed, especially to tackle the uncertainty, the result of our analysis should be treated with care, as the focus of the study was more limited than the identified other literature reviews. Belosevic et al. (2018) offered an explanation regarding the uncertainty (the lack of information, project outputs or limited resources) consideration in the decision-making approaches, namely that actually the problem to be solved is simplified so as to disregard the uncertainty issues.

Regarding the combined/hybrid methods, we also noticed an increase use, being employed in 28 analyzed articles, MCA being used in combination with, for example, CBA, GIS, LCA. Moreover, we could observe a growing interest for the inclusion of the stakeholders in the decision-making technique: the so-called multi-actor multi-criteria analysis (MAMCA) (Cornet et al., 2018; Roukouni et al., 2018), group decision-making (Belosevic et al., 2018; Zak et al., 2014), or Competence-based Multi-Criteria Analysis (COMCA) (te Boveldt et al., 2018).

In the majority of the articles, the methods were applied as ex-ante analysis (before the implementation of the project) and only in three articles as an ex-post analysis (Salling et al., 2004; Thomopoulos & Grant-Muller, 2013; Zembri-Mary, 2017). Therefore, it seems that MCA is mostly used for decision-making related to planning of infrastructure development, rather than to assess decisions made previously, a conclusion supported by Deluka-Tibljas et al. (2013), as well. However, in the context of increased attention given to environmental protection (in its larger sense, including the adaptation and mitigation measures of climate change) and the increased use of LCA, we believe that MCA will be applied in all of the stages of life-cycle stages of infrastructure projects and more environmental criteria will be used (or at least having a higher weight). Also in this setting, in the construction planning phase, the efficient use of resources and the materials to be used will play a bigger role.

5.2. Criteria

The first step in analyzing the criteria was to categorize the papers according to the transport mode (leading up to 7 categories), due to the high number of papers. Very few articles included sub-criteria in their assessment framework and only one articles had sub-sub-criteria (Olesen & Barfod, 2018).

We noticed the predominance of criteria belonging to the 3 pillars of the sustainability, sometimes associated with the transportation category, as well, but there is a very high degree of variability in terms of their indicators. Moreover, the criteria were divided among monetary (mostly related to CBA) and non-monetary (Ambrasaite et al., 2011; Guhnemann et al., 2012; Olesen & Barfod, 2018), but also according to the phase of the project, namely implementation and operation (Nguyen et al., 2017). In addition, in relation to the discussion of involving the stakeholders in the decision-making process, there are papers in which different criteria were used for different stakeholder groups, in the urban infrastructure projects category (Roukouni et al., 2018; te Boveldt et al., 2018). Due to the fact that infrastructure projects are very complex and characterized by often conflicting objectives of their stakeholders, this approach of presenting the stakeholders with different criteria could help in finding a middle ground and contribute to a better integration of their judgement and finally to better outcomes. Therefore, we believe that the group/stakeholder MCA will be used more often in the future. In addition, the list of criteria to be part of the decision-making methods could evolve, as the policy is changing and more funding programs will adapt their awarding criteria, leading to an intense use of Policy-Led Multi-Criteria Analysis (PLMCA).

The accessibility or the integration with other modes of transport criteria could be seen in the articles where there was a focus on a corridor project or the project had a cross-border dimension (Tsamboulas, 2007; Martinov, 2018; Vulevic et al., 2018; Zgaljic et al.; 2019).

The innovation criteria appear in only two articles, although related to financial mechanisms (VCF and public private partnership) (Tsamboulas et al., 2013; Roukouni et al., 2018), and only one article was touching upon the technological criteria (Kolosz et al., 2013). We expect the innovation and technology criteria to appear in more papers in the future, not only because of the policy reasons, but also because of the take-up of the new technologies and solutions in these projects.

Thomopoulos & Grant-Muller (2013) included equity criteria and Glavinov et al. (2012) the defence and system of civil protection (defined as linking the defence directions). The latter might be expected to be more present in the future assessment as some EU programs (for example, Connecting Europe Facility 2021-2027) could allocate a budget for funding twin-use civilian-military transport infrastructure (European Commission, 2019b).

Regarding the equity criteria (or the intergenerational redistributive effects, as called in Penalver&Turro, 2018), although an important part of the debate regarding the implementation of transport projects in the context of sustainability, it was not used on a big scale.

5.3. Environmental criteria and indicators

As we argued in the introduction of this study, the environmental criteria indicators had a broad range of variation. Although the vast majority of indicators could be grouped under „resources" category, we identified some indicators belonging to climate change (adequacy of flood) and (efficient/sustainable) consumption of the resources (e.g. fuel consumption, energy consumption, energy saving, material footprint, energy used per task or resource, consumption of natural resources (fuel consumption and green spaces destruction and land consumed for transport)). However, we cannot state that the criteria related to climate change are widely employed, but we agree with the conclusion of Penalver&Turro (2018) that the effects on climate change were not among the popular ones. Moreover, in line with the indicators monitored by the European Environment Agency in the transport sector, we could find in articles references to the measurement of Greenhouse Gas emissions, emissions of air pollutants, use of renewable energy for transport (in Europe) or noise exposure. We expect the emergence of more environmental indicators in relation to circular economy, renewable energy consumption and to mitigation and adaptation measures regarding climate change once the new EU funding programs will be in place, reinforcing the Green Deal's policies objectives.

Nonetheless, we discovered that the environmental criteria were not included, but mostly technical criteria were considered, when applying MCA decision-making techniques to modernization / rehabilitation / improvement / renewal railway infrastructure projects (Macura et al., 2012; Montesinos-Valera et al., 2017; Couto et al., 2018). We believe that these cases in which the environmental criteria will not be part of the assessment framework will be fewer, not only due to the environmental-focus policies, but also due to the combination of MCA with more sustainability assessment methods, such as LCA.

As the environmental criteria was in the center of interest for this article, an extensive list of environmental indicators is provided as well.

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