Journal of Supply Chain Management Science

https://journals.open.tudelft.nl/jscms

http://dx.doi.org/10.18757/jscms.2020.4651

Importance of freight mode choice criteria: An MCDA approach

Lorant Tavasszy *, Geerten van de Kaa, Wan Liu

Faculty of Technology, Policy and Management, Deft University of Technology, 2628 BX, Delft, The Netherlands

Received 22-02-2020, accepted 02-04-2020

Abstract – Road transportation has been the dominant mode for inland freight transportation for decades. Rail and waterways transportation are less frequently used alternatives, but in general more attractive from an environmental perspective. Even though many policies promoting the use of intermodal transportation have been proposed, they have had little impact to trigger shippers to shift mode from road transportation to rail or inland waterways transportation. One main reason might be that the requirements of shippers towards transportation modes are still not well understood. Hence this research investigates freight transportation mode choice with a new approach, multi-criteria decision analysis, as well as from the perspectives of different types of industries and experts. Reviewing the literature, the requirements for transportation modes are abstracted into a set of criteria, including transportation cost, door-to-door travel time, on-time reliability, flexibility, frequency, and reduction of CO2 emissions. As the importance of these factors might be different for different industries, we consider four segments: the manufacturing industry, the agriculture industry, the perishable food industry, and the chemical industry. Data from practitioners, industry experts, and academics are collected via online questionnaires and analyzed using the 'best worst method' (BWM) to identify weights for the mentioned criteria. The results indicate that transportation cost is viewed as the most important, closely followed by on-time reliability, while reduction of CO2 emission is viewed as the least important. Several comparison studies are conducted to see any difference in the importance of these factors with respect to different industries or respondent groups.

Keywords: Freight transportation mode choice; intermodal transportation; multi-criteria decision analysis (MCDA); best worst method (BWM)

1. Introduction

Driven by rapid global industrialization and ever-increasing demand for freight movements, freight transportation has become a major source of the external costs of transportation. Among the freight transportation modes, the most commonly used mode is road transport, responsible for about 75% of the total inland freight transportation in the European Union (Eurostat, 2017). Road freight transportation causes comparatively high external costs, including environmental costs, infrastructure, congestion and road safety costs. In order to reduce the negative consequences of transport, public authorities have attempted to spur transportation decision-makers to switch to alternative modes. For example, in 2001, the European Union proposed a White Paper including a policy to shift surface freight transportation flows from unimodal road transportation to rail and waterways transport. It is widely agreed amongst researchers and policy makers, that an understanding of the factors determining mode choice is important to develop effective policies (Larranaga et al., 2017). When making the modal choice decision, shippers assess transportation modes based on several choice criteria such as transportation cost and door-to-door travel time. The relative importance of these criteria plays an important role in the transportation modal choice decision.

Research on factors determining mode choice goes back to the 1960's, including micro-economic studies to understand how decision-makers value transportation service attributes. Along the lines of the "abstract

* Corresponding author. Email address: l.a.tavasszy@tudelft.nl

modes" approach of Quandt and Baumol (1966), the overwhelming majority of the literature has focused on the use of multi-attribute, compensatory utility functions and the related random utility, discrete choice models. This model type has become the mainstream approach to transportation model choices. The most recent reviews of the literature on freight transportation mode choice (see, e.g., Feo-Valero et al., 2011c; Arencibia et al, 2015) focus exclusively on this type of models. Surprisingly, the question to what extent multi-criteria decision analysis (MCDA) can provide a viable empirical alternative for RUM-DC approach has largely been left untouched.

MCDA has appealing properties that may make its use favorable in policy practice. These include a background in decision theory2 which allows it to be positioned scientifically next to the mainstream methods. In addition, its simple mathematical structure implies that it is easy to communicate to non-expert policy makers and practitioners in the field. Especially in cases of multi-stakeholder decision making, simplicity of models is an important for face validity and, thus, acceptance. In general, MCDA methods, as expert-based methods compared to statistical methods, are less vulnerable to adding or excluding a data point and they are less data-extensive (Rezaei et al., 2012). Usually, MCDA methods can produce statistically stable results from a limited sample of experts. In addition, data collection per interviewee requires a mild effort compared to the computer assisted personal interviews (CAPI) typically held in modal attribute valuation studies.

There is only a handful of papers in the literature that considers MCDA inspired weighting frameworks for mode choice. Only one of these studies reports tractable empirical results that aim to characterize a wider population of freight actors. Witlox and Vandaele (2005) and Beuthe et al. (2005) describe the use of the UTASTAR method to derive weights for 98 firms, for 6 mode attributes based on a stated preference (SP) and ranking survey dataset. The criteria considered do not include environmental impacts. Tuzkaya and Önüt (2008) apply a fuzzy ANP model to infer these weights from interviews for 32 attributes among managers of a single logistics service provider in Turkey. Macharis et al. (2009) and Simongáti (2012) both discuss the idea of using MCDA in a broader evaluation framework but do not present empirical findings. Neither of these studies considers the merits of alternative MCDA approaches, compares the performance of the MCDA approach to a conventional DC-RUM approach, or provides statistics that could be used to do this comparison ex post. Our aim is to contribute to filling this gap with an MCDA based empirical investigation of the importance of freight mode choice criteria.

The contributions of the paper are as follows:

- The paper contributes to filling the MCDA application gap in the literature, by adding empirical research that uses the Best-Worst Method.
- It provides empirical results with new values for attribute weights, which adds to existing range of values.
- It provides values for the relative importance of CO_2 emission as a decision criterion.
- Different types of experts are considered, including scientists and practitioners.

The paper is organized as follows. This introduction is followed by a literature review of mode choice criteria and modelling approaches, positioning our work and providing material for comparison. Section 3 describes the proposed methodology, while Section 4 presents its application, including the results of analyzed data and the interpretation of the estimations. Finally, conclusions and recommendations are presented in Section 5.

2. Literature Review

The two main areas of focus of this review are the factors (criteria) which are used to choose a transportation mode and the weights assigned to these criteria. We provide a brief account of the consensual list of criteria that has developed over decades of research and summarize the findings on the relative importance of these criteria.

Regarding the criteria of freight transportation mode choice, the most commonly mentioned by researchers are transportation price, door-to-door travel time, frequency, flexibility, on-time reliability, and damage or loss (Jeffs

[2] "Decision theory is the theory of rational decision making [...] the ultimate aim of decision theory is to formulate hypotheses about rational decision making that are as accurate and precise a possible" (Peterson, 2009, pp. 1-2).

and Hills, 1990, Marcucci and Scaccia, 2004, Zotti and Danielis, 2004, Witlox and Vandaele, 2005, Punakivi and Hinkka, 2006, Bergantino and Bolis, 2007, Feo-Valero et al., 2011a). Zhang et al. (2005), Fries and Patterson (2008), Fries (2009), Lammgård (2007), and Regmi and Hanaoka (2015) argue that the environmental factor - CO2 emissions - should be included due to the increasing societal concern about climate change. Interestingly, despite the use of the environmental perspective to justify this research, environment-related factors are rarely included into the set of criteria. Table 1 summarizes the appearance of these criteria in the literature.

Table 1. Transportation mode selection criteria considered in recent empirical literature

Reference	**Target population**	**Considered modal alternatives**	**Method**	**Door-to-door travel time**	**Transportation cost**	**On-time Reliability**	**Frequency**	**Flexibility**	**Loss & damage**	**CO2-emmission**
Shinghal and Fowkes (2002)	Indian firms from six different product sectors	Road, intermodal, and rail transportation	Logit model	√	√	√	√			
Vannieuwenhuyse et al. (2003)	Flemish shippers and logistics service providers	Road, inland, and rail transport	An interactive Internet tool	√	√	√	√	√	√	
Beuthe et al. (2005)	Belgian shippers	Rail, road, waterways, short-sea shipping and their combinations	UTA-UTASTAR	√	√	√	√	√	√	
Marcucci and Scaccia (2004)	Italian logistics personnel	Train, ship and inter-modality transport.	Multinomial logit model	√	√	√	√	√	√	
Zotti and Danielis (2004)	Mechanics companies in the Italian region	Road and intermodal transport	Multinomial logit model	√	√	√	√	√	√	
Punakivi and Hinkka (2006)	Logistics service providers	Ship, road, air, railroad transportation	Qualitative analysis		√	√			√	
Bergantino and Bolis (2008)	Italian freight forwarders	Road and maritime ro-ro transport	Tobit Maximum Likelihood		√	√	√			
Fries and Patterson (2008)	Canadian shipping managers	Road, rail, and intermodal transport	Qualitative analysis	√	√	√				√
García-Menéndez and Feo-Valero (2009)	Spanish exporters and freight forwarders	Short-see shipping and road transport	Binary logit model	√	√					

Reference	Target population	Considered modal alternatives	Method	Door-to-door travel time	Transportation cost	On-time Reliability	Frequency	Flexibility	Loss & damage	CO2-emmission
Norojono and Young (2003)	Freight companies in Java	Rail and road transportation	Multinomial logit model			√		√	√	
Dalla Chiara et al. (2008)	Italian/French transportation operators	Road only mode and intermodal-rail transportation	Multinomial logit model	√			√			
Feo-Valero et al.(2016)	Spanish producers and distributors	Road and intermodal-rail transportation	Multinomial logit model and mixed logit model	√	√	√	√			
Beltran et al. (2012)	Dutch shippers and logistics service providers	Road, rail, inland waterways	Multinomial logit model	√	√	√				√
Brooks et al. (2012)	Australian shippers	Road, rail, and coastal shipping	Mixed logit and latent class	√		√	√			
Feo-Valero et al.(2011c)	Spanish freight forwarders	Road and maritime-intermodal transportation	Mixed logit model with error	√	√	√	√			
De Jong et al. (2014)	Shippers and carriers in The Netherlands	Road, barge, rail, sea, air	Mixed logit models	√	√	√	√		√	
Wanders (2014)	Dutch shippers and logistics service providers	Road, rail, inland waterways	Multinomial logit model and mixed logit model	√	√	√	√			√
Larranaga et al.(2017)	Shippers and logistics managers from Brazil	Road, Intermodal rail, Intermodal waterway	Multinomial logit, Mixed logit models	√	√	√				

Below we discuss some in more detail the main findings in the literature on the relative importance of criteria.

There seems to be overwhelming evidence for the dominant importance of costs, time and reliability. Their ranking differs between studies, however. Vannieuwenhuyse et al. (2003) investigated the perception of Belgian logistics decision-makers regarding the choice of transportation modes by using a survey, and thus concluded that transportation cost is one of the criteria having the highest weight. This perspective is also underlined by Feo-Valero et al. (2011b) who concluded that transportation cost is the only reason to stimulate shippers who use the hinterland rail connection to shift their transportation mode, and this conclusion is based on the fact that 81% of freight forwarders uses the low cost of the rail transportation as the main reason for their transportation mode choice. Cullinane and Toy (2000) conducted a meta-analysis study about route and transportation mode choice, showing that transportation cost, together with door-to-door travel time and reliability, are consistently referenced and often considered as the most relevant factors. Another extensive survey consisting of 246 interviews with freight forwarders, which is conducted by Grue and Ludvigsen (2006), identified the determinants of mode and route choice in the intra-European freight transportation market. Their results show that the transportation cost and reliability are chosen as the most relevant transportation mode choice criteria. Bouffioux et al. (2006) show that transportation cost with the weight of 64% largely other criteria such as flexibility (6%) and frequency (below 5%), indicating the highly perceived importance of transportation cost. While some of the above researchers agree that transportation cost is the most important criterion, Beuthe et al. (2005) found that other criteria together (excluding cost) are as important as transportation costs. Danielis et al. (2005) conclude that there is a strong preference for other criteria over cost. It is possible that the reason causing this contradiction is that these two studies use different groups of respondents and different methods.

Reviews of the monetary value of door-to-door travel time are provided by Zamparini (2004), Feo Valero et al. (2011) and de Jong et al. (2014). While many studies still look at mode specific and commodity abstract values of time, several authors including Blauwens et al. (2006), Massiani et al., (2007), Fries (2009) and Brooks et al. (2012) argue that the value depends on the customer requirements and product characteristics. Fries et al. (2008) points out that shippers tend to weight on-time reliability about 20-100% higher than transportation cost and up to 14 times higher than door-to-door travel time. At the same time, transportation cost seems to be of higher relevance than on-time reliability only for building materials. Cook et al (1999) found that on-time reliability is the most important factor considered in the modal choice in a study of the Indian freight market, and, especially for shippers of chemical goods which require highly reliable transportation flow, reliability is of particular importance. Moreover, Fries (2009), Grue and Ludvigsen (2006), and Beuthe et al. (2005) also concluded that on-time reliability is the most relevant transportation criterion.

The importance of on-time reliability is influenced by several factors. With the increasing adoption of Just-in-time (JIT) processes in many firms, the on-time reliability is assigned with higher values (de Jong, 2014). The distance also plays an important role in influencing the sensitivity of on-time reliability in such a way that increasing distances will decrease sensitivity in requirements of on-time reliability due to the possible higher delay risk in terms of long distance transportation (Fries, 2009). Moreover, requirements of on-time reliability can also be affected by the characteristics of freights transported. Witlox and Vandaele (2005) mentioned that on-time reliability is particularly important for the company who produces cooling machines, and it even surpasses transportation cost.

Zamparini et al.(2001) defined frequency in terms of the number of shipments offered by a transportation company or freight forwarders in a determined period of time. Frequency also appears to be an important criterion in mode choice, especially for shippers who make frequent and low volume shipments (Shinghal and Fowkes, 2002). The research carried out by Combes (2012) even further strengthens these findings. Based on a survey among French shippers, they found that frequency of shipments plays an important role in determining modal choice and shipment size. García-Menéndez and Martínez-Zarzoso (2004) found that frequency is important due to the growing importance of efficiency in logistics. Dalla Chiara et al. (2008) concluded that high frequency might cause shippers to shift transportation modes. According to Bergantino and Bolis (2007) who conducted the research among Italian freight forwarders, frequency is perceived as the most important parameter together with on-time reliability.

Flexibility is defined as the ability of a company to respond quickly and efficiently to changing customer needs in inbound and outbound delivery, support, and services (Day, 1994). While, in the literature of freight transportation modes, it is often defined as the number of unplanned shipments which are operated without excessive delay. Flexibility is commonly included as a quality criterion in literature (Bolis and Maggi, 2003, Witlox and Vandaele, 2005, Vannieuwenhuyse et al., 2003, Marcucci and Scaccia, 2004, Zotti and Danielis, 2004, Massiani, 2007). It appears that the importance of flexibility always turns out lower than criteria like transportation cost and door-to-door travel time. Flexibility is a quality criterion, whereas it is also estimated in terms of monetary value in the research of Zamparini et. al. (2001). Their research mentions that flexibility seems to be an irrelevant criterion regarded by a sample of Tanzanian firms.

Few studies consider CO_2 emission as an important criterion deciding the freight transportation mode choice. Most conclude that the importance of CO_2 emission is the least significant in comparison with other criteria. Platz (2008) concluded that shippers only consider environmental benefits for marketing or public relations purposes. Lammgård (2007) concludes that CO_2 emission was taken into account to a high degree. In a survey of container transportation in port hinterlands, Beltran et al. (2012) found that CO_2 emission has a significant willingness-to-pay for its decrease, well above current market prices. Fries (2009) concluded that Swiss shippers are willing to pay for CO_2 emissions reduction. Feo-Valero et al. (2011b) found no freight forwarders who actually consider the environmental perspective as a reason to shift towards the rail transport. Beltran (2012) and Wanders (2014) measure CO_2 emission importance for Dutch shippers and carriers, but these studies have not been published in the scientific literature. The fact that the CO_2 emission has only been considered in a few studies, and that it has low importance even when it has been considered as a mode choice criterion, shows that this is not a determinant criterion for (most) shippers. It can also be due to the more recently global attention to climate change and environmental impacts of transportation (Centobelli et al., 2017). However from the point of view of policy makers and government, CO_2 emission is an important factor that needs to be considered (Anderson et al., 2005). Therefore we choose to include it.

Damage and loss are defined in terms of the percentage of commercial value loss due to damage, theft, and accidents (Witlox and Vandaele, 2005). Some previous studies also consider safety and security to be aspects of quality, and thus the absence of loss and damage play a pivotal role in freight transportation mode choice. Patterson et al. (2007) found that the damage and loss are ranked higher than on-time reliability and transportation cost. Besides, Witlox and Vandaele (2005) also emphasized the importance of eliminating loss and damage in the decision of mode choice given that each damage and loss represents a tangible loss in terms of the value of freights, and the conclusion is that the more handling operations the freight transportation includes, the higher the chance of loss or damage is. While, from the other side, the research of Feo-Valero et al. (2011a) shows that there is a diminishing interest in the damage and loss criteria since the improved transportation technology and infrastructure and the widely-used containers largely increase the level of freight transportation service, and underlines that the use of containers has a positive impact to eliminate damage and loss. Furthermore, Danielis and Marcucci (2007) even underlined that shippers are willing to tolerate a minimal damage and loss. Thus, the conclusion can be drawn that due to the increasing use of containers, damage and loss risks are largely eliminated from freight mode choice considerations.

Transportation cost and door-to-door travel time are largely incorporated in previous literature as important criteria in freight transportation mode choice. In the next place, the importance of on-time reliability, frequency, and flexibility have been consistently approved by most existing literature, while CO_2 emission is barely mentioned in existing literature. However, rising concerns of society for CO2 emission can no longer be ignored, and companies, nowadays, have a moral obligation to adopt the sustainable way to operate their business. Besides, customers appear to value the green image that companies present and to be aware of the considerable effect of CO_2 emission the road transportation generates. Hence, decision-makers may want to incorporate CO_2 emission to an increasing degree as an important criterion. Therefore, reduction of CO_2 emission will become an important criterion considered in the future research, and by measuring respondents' preferences towards it, it can be explicitly seen whether respondents are willing to reduce CO_2 emission. To conclude, this research includes reduction of CO_2emission as a criterion together with other five criteria which are transportation cost, door-to-door travel time, flexibility, frequency, and on-time reliability. The damage and loss risk will not be incorporated in this research mainly due to two reasons: (i) since this research studies the freight transportation mode choice under the situation that containers are used as loading units to carry freight, and in the same line of reasoning concluded by Feo-Valero et al. (2011a) the use of containers eliminates the appearance of loss and damage, or largely reduce the possibility of damage and loss to the minimal level that decision-makers are willing to tolerate (Danielis and Marcucci, 2007); (ii) with respect to the tighter regulation of cargo screening and more attention paid to freight transportation, the safety and security of freights is no more of an issue today (Roberts, 2012), which further ensures the absence of damage and loss in freight transportation. So, it can be concluded that given the setups of this research where containers are used during freight transportation, the importance of damage and loss to the transportation modal choice is diminished so that damage and loss is not chosen as the important criterion in this research.

A general finding for all criteria is that the characteristics of products and shipments play an important role. We will distinguish between four types of products, from the manufacturing industry, the agriculture industry, perishable foods, and chemical products. The example products provided to the expert to illustrate the industries were machines, grain, chilled meat and unitized (containerized or palletized) chemical goods. Literature points towards transportation cost, on time reliability and door-to-door travel time as the three most important criterion for all the industries we consider (Vannieuwenhuyse et al., 2003, Danielis et al., 2005, Fries et. al., 2008, Cullinane and Toy, 2000). Frequency and flexibility might be more important for the agriculture industry, perishable foods compared to the other two industries, while CO2 reduction might be more important for the chemical industry compared to other industries (Fries, 2009).

In our study, we have focused on an empirical application of an MCDA method among transportation experts and practitioners, to identify weights for the most common mode choice criteria. The next section introduces in more detail the MCDA method chosen and the data collection approach.

3. Methodology

There are several MCDA based weighting methods in literature; we refer the interested reader to Triantaphyllou (2000) and Greco et al. (2005) for reviews. Best Worst Method (BWM) (Rezaei, 2015, 2016) is a relatively new MCDA method. We choose to apply this in this study due to its data efficiency, structured way of comparison, high reliability of its results and user friendliness. BWM has been successfully applied to several multi-criteria analysis problems such as supplier selection and segmentation (Rezaei et al., 2015, Rezaei et al., 2016, Gupta and Barua, 2017, 2018, Haeri et al., 209, Rezaei and Fallah, 2019), freight bundling configuration (Rezaei et al., 2017), renewable energies (Kheybari et al., 2019a, 2019b), circular economy (Moktadir et al., 2020), technological innovation (Gupta and Barua, 2016), business continuity management systems (Torabi et al., 2016), water scarcity management (Chitsaz and Azarnivand, 2017), airline service quality assessment (Gupta, 2018), supply chain sustainability (Wan Ahmad et al., 2017, Ahmadi et al., 2017), assessment of scientific outputs (Salimi, 2017), firm's R&D performance assessment (Salimi and Rezaei, 2018), and technology selection and assessment (van de Kaa et al., 2017a,b, Ren et al., 2017, Ren, 2018).

The method is described in the following section. Following Rezaei (2015, 2016), the BWM can be described in five steps, as follows.

Step 1. A set of evaluation criteria $\{c_1, c_2, \ldots, c_n\}$ is identified. For example, in this research, the set of evaluation criteria is:

$$\left\{\begin{array}{c} c_1: transport\ cost; \\ c_2: door - to\ door\ travel\ time; \\ c_3: on\ time\ reliability; \\ c_4: flexibility; \\ c_5: frequency; \\ c_6: reduction\ of\ CO_2\ emission \end{array}\right\}$$

Step 2. The best criterion (e.g. most desirable, most important) and the worst criterion (e.g. least desirable, least important) should be determined. The input is gathered using the below table format (table entries showing an example result)

Table 2. Format for recording best and worst criterion

Factors	Most Important	Least Important
Transportation cost		
Door-to-door travel time	x	
On-time reliability		
Flexibility		x
Frequency		
Reduction of CO2 emission		

Step 3. The preference of the best criterion over all the other criteria should be determined by using a number between 1 and 9 where 1 means equal preference between the best criterion and another criterion, and 9 means the extreme preference of the best criterion over another criterion. The result of this step is the vector of Best-to-Others:

$$\boldsymbol{A_B} = (a_{B1}, a_{B2}, \ldots, a_{Bn}) \qquad (1)$$

where a_{Bj} indicates the preference of the best criterion B over criterion j.

Inputs were gathered using the below table format (numbers following example of step 2).

Table 3. Input format for Best-to-Others step*

Factors	Transportation cost	Door-to-door travel time	On-time reliability	Flexibility	Frequency	Reduction of CO2 emission
Most important	3	1	2	9	5	7

* Definition of 1 to 9 measurement scale:
1: Equal importance 3: Moderately more important 5: Strongly more important 7: Very strongly more important
9: Extremely more important 2,4,6,8: Intermediate values

Step 4. The preference of all criteria over the worst criterion is determined by using a number between 1 and 9. The result of this step is the vector of Others-to-Worst:

$$\boldsymbol{A_W} = (a_{1W}, a_{2W}, \dots, a_{nW})^T \quad (2)$$

where the a_{jW} indicates the preference of the criterion j over the worst criterion W.
Inputs were gathered using the below table format (numbers following example from table 2).

Table 4. Input format for Others-to-Worst step*

Factors	Least important
Transportation cost	7
Door-to-door travel time	9
On-time reliability	8
Flexibility	1
Frequency	5
Reduction of CO2 emission	3

* Definition of 1 to 9 measurement scale:
1: Equal importance 3: Moderately more important 5: Strongly more important 7: Very strongly more important
9: Extremely more important 2,4,6,8: Intermediate values

Step 5. The optimal weights ($w_1{}^*, w_2{}^*, w_3{}^*, \dots, w_n{}^*$) should be calculated. The optimal weights of criteria should satisfy the following requirements:
For each pair of w_B/w_j and w_j/w_W, in an ideal situation $w_B/w_j = a_{Bj}$ and $w_j/w_W = a_{jW}$. Therefore, for all j, we minimize the maximum among the set of $\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_w|\}$, The problem can be formulated as follows:

$$\begin{aligned} &\min max_j \{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_w|\} \\ &\quad \text{subject to} \\ &\quad \textstyle\sum_j w_j = 1 \\ &\quad w_j \geq 0, \text{ for all } j \end{aligned} \quad (3)$$

Problem (3) can be transferred to the following linear programming problem:

$$\begin{aligned} &\min \xi^L \\ &\quad \text{subject to} \\ &\quad |w_B - a_{Bj}w_j| \leq \xi^L, \text{ for all } j \\ &\quad |w_j - a_{jW}w_W| \leq \xi^L, \text{ for all } j \\ &\quad \textstyle\sum_j w_j = 1 \\ &\quad w_j \geq 0, \text{ for all} \end{aligned} \quad (4)$$

Solving problem (4) provides a unique set of optimal weights ($w_1{}^*, w_2{}^*, w_3{}^*, \dots, w_n{}^*$) and ξ^{L*}. ξ^{L*} is an indicator of the consistency of the comparison system, and the closer the value of ξ^{L*} is to zero, the higher the consistency is, and thus the more reliable the comparisons become.

Primary data was collected through a questionnaire that exactly followed the lines of the stepwise method.. Three types of respondents are considered in this research, including practitioners (logistics industry professionals), industry experts (independent consultants), and scholars (mostly university professors).

Practitioners refer to people who not only make freight modal choice decision but also use their own transportation modes to transportation freights, which means they do not outsource the freight transportation to other companies. Therefore, according to the aforementioned findings from the research of Fries and Patterson (2008), practitioners, in this research, can thus be represented by private shippers and carriers. Industry experts in this research are defined as a group of people who work in a third-party-logistics company or logistics consultancy company and do not transportation freights themselves, such as freight forwarders who organize shipments by outsourcing freights transportation. The reason for particularly dividing actual decision-makers into two groups-industry experts and practitioners- is that these two types of decision-makers have a different focus regarding freight transportation demand when considering freight transportation mode (Fries and Patterson, 2008), and due to different working environments and capacities, people representing industry experts, such as freight forwarders, often play a role as experts in logistics-related decision-making processes, while practitioners, such as carriers, tend to work in the field and thus might not see the whole decision-making process in a strategic way that industry experts do. In addition, compared to practitioners, industry experts acquire more logistics-related know-how and professional perspectives, while compared to professors, industry experts have more practical knowledge and freight transportation-related working experience. Thus, industry experts can even be viewed as the interface between practice-focused practitioners and technology-focused professors. Therefore it is interesting to know how industry experts actually perceive the criteria when making a decision of freight transportation mode.

While scholars specialized in logistics-related fields might have relatively little practical experience with the mode choice decisions, they do have the latest information, scientific methods and a holistic overview of technologies and logistics. This suggests that they can approach modal choice decision by considering more aspects than those perceived by practitioners and industry experts. Correspondingly, scholars generally get updated information, such as survey data, from interviews with practitioners and industry experts. To conclude, people from different working backgrounds might perceive the criteria differently and thus assign different importance to specific criteria. Especially since existing studies mostly only choose practitioners as the target population, it might be informative to know how other experts perceive the criteria. Comparing the importance of criteria perceived might present a more comprehensive picture and interesting perspectives for future study of freight transportation modal choice.

LinkedIn was used for collecting respondents by using its built-in searching engine to find the relevant respondents having logistics and transportation related titles, following a structured approach to ensure the respondent is relevant to this research, for example by using relevant search keywords and screening functions in companies. At the end, 1072 respondents (from Europe and North America) are selected in total, which include 555 practitioners, 317 industry experts, and 200 professors. E-mails were sent to the potential respondents containing a link to a survey prepared with the online tool SurveyGizmo®. The questionnaire was sent separately into the three groups and the data collection process ran for two months. In total 51 have responded, of which 1 questionnaire is excluded because of missing data. Among the remaining 50 valid responses there were 20 practitioners, 16 professors, and 14 industry experts. In the following we present and discuss the outcomes of the analysis.

4. Results and discussion

In this section, the collected data is analyzed by using BWM; weights are obtained for all criteria including indicators for consistency and standard deviation. As mentioned before, six criteria are incorporated in this research, which are transportation cost, door-to-door travel time, on-time reliability, flexibility, frequency, and reduction of CO_2 emission. Table 2 presents the final results from collected survey by using BWM method. It included three segments which are: *i*) overall results; *ii*) results based on three types of respondents; *iii*) results based on four types of industries.

The first segment of the table, visualized in Figure 1, is generated by considering results from all respondents and all industries, therefore there are six overall weights regarding six criteria. In the second segment results are grouped with regard to three types of respondents; see also Figure 2. The third segment of the table partitions the results based on four groups of industries; see also Figure 3. In addition, the ranking of weights of all criteria from one industry can be compared to the one from another industry.

Table 5 includes average weights, standard deviation, and consistency (ξ^{L*}). As mentioned in the methodology section, the higher the average weight of a criterion indicates that this criterion is viewed as more important compared to the other criteria, and the more closer the value of the consistency ξ^{L*} to zero the more reliable the results are.

Table 5. Mean weights and standard deviation of criteria

Respondents	Transportation Cost	Travel time	On-time Reliability	Flexibility	Frequency	Reduction of CO2 emission	Consistency (ξ^{L*})
All respondents	0.246	0.206	0.242	0.123	0.112	0.07	0.116
(*n* = 50)	(0.127)	(0.109)	(0.11)	(0.063)	(0.051)	(0.064)	(0.087)
Results based on three types of respondents							
Industry experts	0.240	0.228	0.243	0.106	0.114	0.069	0.14
(*n* = 14)	(0.134)	(0.12)	(0.11)	(0.042)	(0.053)	(0.068)	(0.106)
Professors	0.27	0.186	0.234	0.113	0.1	0.097	0.111
(*n* = 16)	(0.129)	(0.098)	(0.118)	(0.044)	(0.043)	(0.083)	(0.072)
Practitioners	0.232	0.208	0.248	0.143	0.118	0.051	0.104
(*n* = 20)	(0.12)	(0.086)	(0.104)	(0.079)	(0.055)	(0.029)	(0.082)
Results based on four types of industries							
Manufacturing	0.279	0.174	0.237	0.135	0.103	0.071	0.115
(*n* = 50)	(0.118)	(0.086)	(0.113)	(0.08)	(0.052)	(0.061)	(0.088)
Agriculture	0.279	0.218	0.2	0.116	0.114	0.074	0.107
(*n* = 50)	(0.124)	(0.102)	(0.082)	(0.059)	(0.053)	(0.078)	(0.09)
Perishable foods	0.135	0.272	0.278	0.128	0.126	0.061	0.115
(*n* = 50)	(0.06)	(0.102)	(0.098)	(0.063)	(0.052)	(0.044)	(0.09)
Chemical	0.293	0.160	0.254	0.114	0.102	0.076	0.127
(*n* = 50)	(0.126)	(0.073)	(0.128)	(0.042)	(0.046)	(0.07)	(0.083)

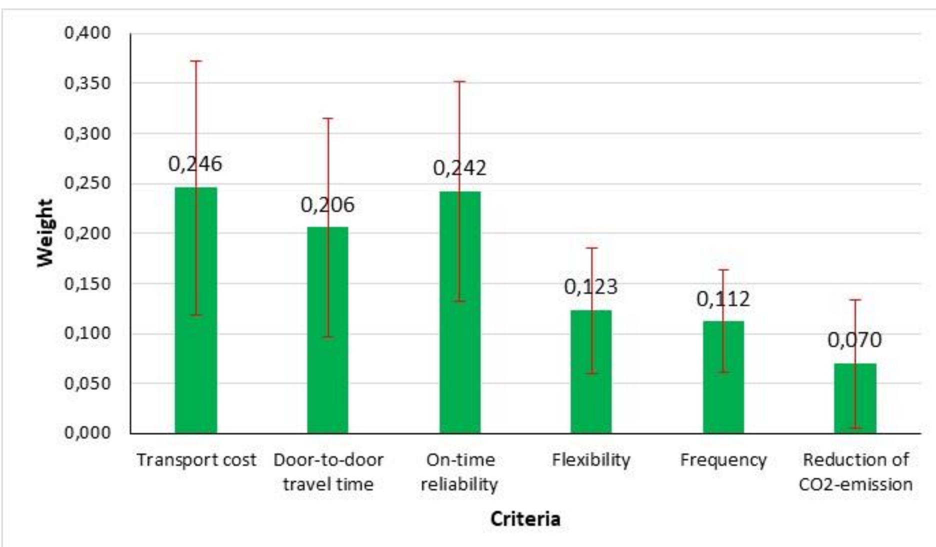

Figure 1. Overall weights of the six criteria (*n* = 50)

Clearly, transportation cost and reliability are together viewed as the most important criteria, with the average weight of 0.246 for cost, and 0.242 for on-time reliability. Broadly, this is in line with the literature (Vannieuwenhuyse et al., 2003, Danielis et al., 2005). It is interesting to observe that service quality variables together carry more than 3/4th of the weight, as opposed to the costs for the shipper. Door-to-door travel time is almost equally important as time, with the weight of 0.206, in line with the research of Fries et. al. (2008). The finding of this top-three is also consistent with Cullinane and Toy (2000) who conducted a meta-analysis study and concluded that these three criteria are consistently referenced and often considered as most relevant factors.

Our findings contrast with Beuthe et al. (2005) who conclude that all other criteria (excluding cost) together have about the equal weight as transportation cost alone. In our research the weight of transportation cost (0.246) just slightly exceeds the on-time reliability (0.242), not to mention another quality criterion - door-to-door travel time - which has the weight of 0.206. This divergence might be caused by the different underlying methodology of surveys, and the method used in Beuthe et al. (2005) requiring monetary values to be assigned to criteria, which might makes respondents tend to care more about transportation cost. In our case, without assigning any monetary value to the criteria, the summed weights of quality criteria are higher than the weight of transportation cost.

Ranked as the fourth important criterion, flexibility (0.123) is slightly more important than frequency (0.112), but both the weights of these two criteria largely exceed the weight of reduction of CO2 emission (0.07). The finding that flexibility (0.123) is less important goes against the conclusion drawn by Norojono and Young (2003) which indicates that flexibility is found to be very significant in determining the freight transportation mode choice and even mention that improving flexibility for particular modes might result in considerable improvements in the use of that mode. However, the finding of flexibility in this research is in line with the research of Zamparini et al. (2001), as described above. Also, the finding that frequency gets relatively low importance, especially compared to on-time reliability which has almost double the weight of frequency, deviates from the result of Bergantino and Bolis (2008) where frequency is perceived as the most important parameter together with on-time reliability. In contrast, the research of Bouffioux et al. (2006) shows that frequency is viewed by shippers as the least important with the weight below 5%, and the weight of flexibility (6%) slightly overruns it, which is quite in line with the relative ranking between flexibility (12.3%) and frequency (11.2%) in this research.

It can also be seen that reduction of CO2 emission gets the lowest weight, which is also in line with the outcomes of existing literature. One should note that, even though reduction of CO2 emissions is of interest to stakeholders such as governments and academia, the general results are largely affected by industry professionals since the number of practitioners and industry experts (34) largely exceeds the number of university professors (16). In addition, it is worth mentioning that the consistency of the general result is quite high.

Even though from Table 2 various differences can be found between different respondent groups and the four industries, in order to know whether these differences are statistically significant, several comparison analyses are conducted, using the Signed-Rank Test and Mann-Whitney U Test. These non-parametric tests are chosen because of the small sample size, which implies that the normality assumption required by the parametric test cannot be tested and supported. Moreover, because three groups of participants have a different sample size, the analysis regarding three groups of respondents is done with the Mann-Whitney U Test. The Signed-Rank Test is chosen for the comparison analysis across four types of industries, as the groups of industry have the same sample size.

When considering all industries, the top-three ranking of criteria differs among three types of respondents. For industry experts, on-time reliability and transportation cost are both viewed as the most important, and the third important criterion is door-to-door travel time. In contrast to industry experts, professors rank transportation cost as the most important, followed by the on-time reliability, and perceive the door-to-door travel time as the third important criterion. Practitioners view on-time reliability as the most important criterion, followed by transportation cost, and they view the door-to-door travel time the third important. As usual, reduction of CO2 emission still gets the lowest importance from the perspectives of all respondents, even though professors give a relatively higher importance to it (see Figure 2). Table 3 shows the p-values of the Mann-Whitney U Test; p-values less than 0.05 shows a statistically significant difference between two corresponding groups.

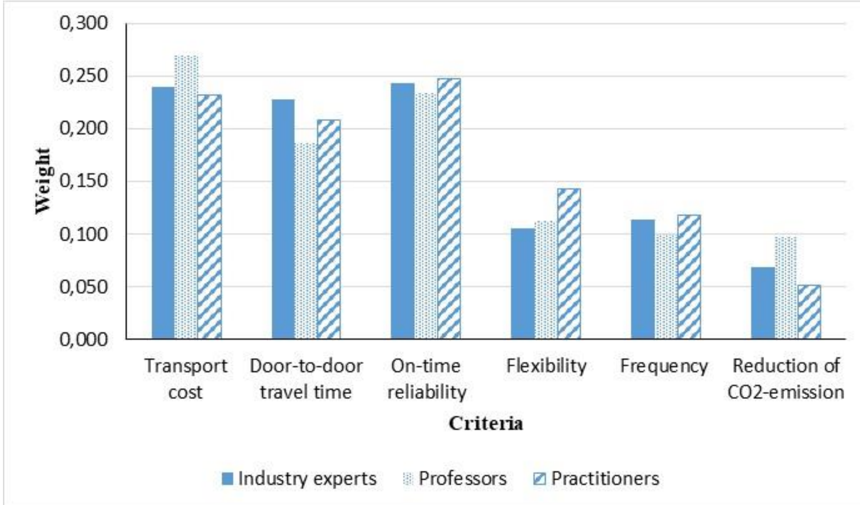

Figure 1. Importance of criteria based on different type of respondents

Table 6. The p-values of Mann-Whitney U Test

Four industries	Transportation cost	Door-to-door travel time	On-time reliability	Flexibility	Frequency	Reduction of CO2 emission
Industry experts vs. professors	0.184	0.046*	0.645	0.214	0.239	0.159
Industry experts vs. practitioners	0.779	0.689	0.844	0.021*	0.707	0.197
Professors vs. practitioners	0.053	0.022*	0.189	0.247	0.086	0.002*

* $p < 0.05$ shows significant difference between the two corresponding groups

Overall, few comparisons lead to a significant difference. It can be seen from Table 6 that practitioners and academics' perceptions differ for door-to-door travel time and also for reduction of CO2 emission. The literature on CO2 emission valuation also shows divergent results (see, for example, Lammgård, 2007, Konings and Kreutzberger, 2001, and Feo-Valero et al., 2011b); we could not trace these differences back to the underlying survey respondents in these studies, however. Possibly, the relatively high importance attached to reduction of CO2 emission and costs by professors is compensated by the relatively low weight for travel time. The perception of industry experts and the perception of practitioners differ regarding flexibility. Also here, the literature provides divergent valuations but does not shed any light on this difference. Our conjecture is that practice could be changing compared with conventional knowledge towards a higher valuation of flexibility. New research would be needed to assess this idea.

Figure 3 shows the scores differentiated by industry. Table 7 shows the p-values of the Signed-Rank Test; p-values less than 0.05 shows statistically significant difference between the two corresponding groups.

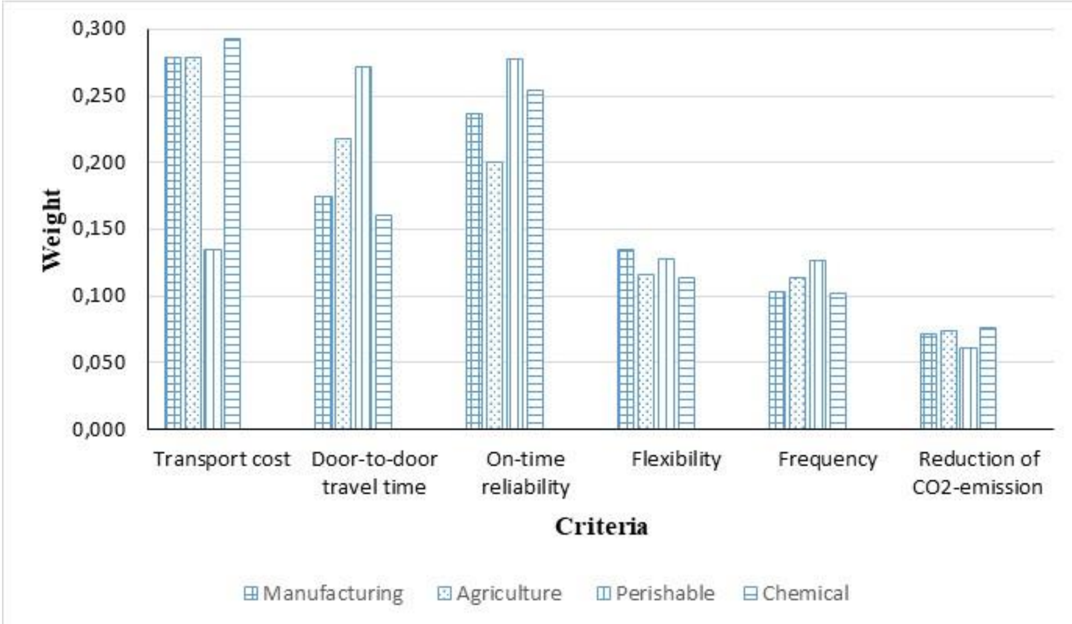

Figure 2. Importance of criteria based on different industries

Table 7. the p-values of the Signed-Rank Test

Hypothesis Test Summary	**Transportation cost**	**Door-to-door travel time**	**On-time reliability**	**Flexibility**	**Frequency**	**Reduction of CO2 emission**
Manufacturing vs. agriculture	0.363	0.010*	0.770	0.078	0.041*	0.307
Manufacturing vs. perishable food	0.000*	0.000*	0.013*	0.978	0.002*	0.004*
Manufacturing vs. chemical	0.035*	0.775	0.227	0.191	0.846	0.386
Agriculture vs. perishable food	0.000*	0.010*	0.000*	0.004*	0.044*	0.658
Agriculture vs. chemical	0.216	0.001*	0.123	0.645	0.050*	0.626
Perishable food vs. chemical	0.000*	0.000*	0.148	0.461	0.003*	0.074

* $p < 0.05$ shows significant difference between the two corresponding groups

According to Figure 3, for the importance of transportation cost, there is a quite significant difference between the one in chemical industry (highest) and the perishable food industry (lowest), Table 4 shows that this is a statistically significant difference. The importance of transportation cost in manufacturing is similar as the one in agriculture industry, and both of them are significantly different with the one in the perishable food industry. Moreover, it is also shown that the importance of transportation cost in the chemical industry is significantly different from the one in manufacturing industry. The highest importance given to door-to-door travel time is in the perishable food industry, and the lowest one goes to the chemical industry. This finding regarding door-to-door travel time in perishable food industry is in line with conclusion drawn by Feo-Valero et al. (2011c), Fries (2009), Fries et al. (2008) and Rodrigo and Satish (2014).

It is interesting that for door-to-door travel time only one comparison does not have a significant difference which is the comparison between manufacturing and chemical industry, and except for this comparison, other 5 comparisons all have significant differences. Among them, it can be seen that door-to-door travel time is perceived significantly differently across agriculture and perishable foods industry. The finding is in line with the results of Wanders (2014) which underlines that differences in preference regarding door-to-door travel time are found between agriculture freights and perishable foods. Regarding on-time reliability, significant differences exist between the perishable food industry on the one hand and the chemical and manufacturing industries on the other (see Table 4).

All respondents perceive the importance of flexibility in agriculture industry significantly different with the one in perishable food industry, and the one in perishable food industry is higher than the one in agriculture industry. For frequency, except the comparison between manufacturing and chemical industry, other comparisons all have significant differences. The weight is highest in the perishable food industry and in the chemical industry the lowest.

When it comes to the reduction of CO2 emission, its importance in the chemical industry ranks the highest, while its importance in the perishable food industry ranks the lowest. This finding is supported by the research of Fries (2009). In addition, according to Fries, if the freights have higher specific value and are placed in the higher position of the value chain, then shippers tend to be more willing to pay for a reduction of CO2 emission. From our findings, the conclusion can be drawn that when transporting chemical products, decision-makers tend to assign relatively high importance to reduction of CO2 emission. From Table 4 it can be seen that a statistically significant difference exists in the comparison between the importance of reduction of CO2 emission in manufacturing industry and the one in perishable food industry, indicating that respondents seem to consider reduction of CO2 emission significantly differently regarding these two industries.

5. Conclusion and discussion

This paper has studied the criteria that shippers find important in their decision to choose for a freight transportation mode. The literature has been reviewed which resulted in a list of criteria; transportation cost, door-to-door travel time, on-time reliability, flexibility, frequency, and reduction of CO_2 emission. The importance of these criteria has been assessed using the best worst method (BWM). Below we address the contributions of this study and provide recommendations for further research.

The first scientific contribution of this study is that it adds to the few studies that employ MCDA to establish weights for freight mode choice criteria. Earlier studies either have not reported empirical outcomes, did not include environmental performance or used other MCDA methods than the Best-Worst Method employed here. Given the abundance of preference studies that use a discrete choice modelling approach, we argue that there is scope for further elaboration of MCDA-based research on this topic, focusing on a detailed comparison of results, performance of methods and applicability for policy studies. We aim to report such results in later papers.

A second contribution lies in our empirical findings, concerning heterogeneity in valuations between sectors and different types of experts, as well as the valuation of specific criteria. Concerning the latter, our results indicate that CO_2 emission reduction and flexibility of service are valued positively by decision-makers and experts. In addition, the relative weights are dependent on the type of industry. We have stratified our respondents into three types of experts: logistics practitioners, industry experts and scientists. The results are largely consistent, despite a difference on the criteria of CO_2 emissions and flexibility. The differences in preferences between sectors follow our expectations, and may act as a guide to differentiate between commodities in valuation studies.

5.1. Practical implications

The practical implications of this study follow from the above. New results concerning importance of emissions and flexibility provide new information for policy makers. Concerning the other criteria, which have been more intensively treated in the literature, our findings confirm the patterns reported by these studies. This is a reassuring result, and promising in the light of the facts that 1) the research effort associated with a BWM survey is lower than of a discrete choice modelling study and 2) due to the model's simplicity the results are easier to communicate to practitioners.

For policy makers, the following findings are relevant. First, despite the new method, our findings concerning the importance of mode choice criteria are in line with the majority of the literature indicating that reliability, transportation time and costs are the most influential criteria in mode choice. Flexibility comes out as a factor which is valued more highly by practitioners than academics and experts, which may indicate a movement in practice which has not been reported in the literature yet. Second, we also add new findings to the existing studies. Our findings indicate that CO_2 emissions matter. The differentiation across sectors may be relevant for multi-modal transportation policies that build on MCDA type consensus seeking methods. Third, we show that there is a significant heterogeneity between industries, mostly concerning the variables that are the primary areas of intervention from transportation policy: transportation costs and time. Whereas differences between past findings can partly be explained by a difference in sectoral context, until now, there is very little research that attempts to map this heterogeneity. Especially in the case of policies related to unit load markets, for example container transportation in port hinterlands, acknowledging heterogeneity of users behind the uniformity of loading units is important to predict responses of the transportation market users to new policies.

5.2. Future research

Our study provides a second report at measuring preference structures for mode choice decisions using MCDA. It demonstrates that useful numbers can be obtained with a modest and transparent research effort. Possible new research includes a further substantiation of empirical findings, comparison with the incumbent method and elaborate, real life testing of the survey method. Specific points in this regards are the following. Although in this paper we have built a framework of a single layer of criteria, sub-criteria could also be included in the research. Secondly, the different valuations by respondent type may provide an indication of changing practice, compared to conventional knowledge, as in the case of flexibility. Thirdly, as the new BWM method is developing rapidly, we recommend further analysis, in particular of consistency of respondents' comparisons, along the lines of recent research (Liang et al., 2019).

MCDA methods have limitations such as inability to statistically test the significance of the weights of the criteria, weakness in considering the interaction effects between the criteria, and also the subjectivity which is inherent in their measurement structure. Choice modeling suffers comparatively less with respect to these features. Future studies are strongly recommended to further exploit the advantages of MCDA in the area of transportation and logistics, where choice modeling has a traditional dominance. It might also be interesting to see how the strengths of each approach can be incorporated into the other approach.

Another future direction is to consider other choice problems which have a close link to the transportation mode choice as those problems could have, sometimes, significant impact on the mode choice decision or vice versa. Some of these problems are the interconnection between mode choice and economic order quantity (EOQ) (Combes, 2012), and interconnection between mode choice and carrier selection (Meixell and Norbis, 2008).

Acknowledgement

We are grateful for guidance for the research in the form of supervision of the second author by dr. Jafar Rezaei of Delft University of Technology and for comments of two anonymous referees

References

Ahmadi, H. B., Kusi-Sarpong, S. and Rezaei, J. (2017) 'Assessing the social sustainability of supply chains using Best Worst Method. Resources', *Conservation and Recycling*, 126, 99-106.

Anderson, S., Allen, J. and Browne, M. (2005) 'Urban logistics–how can it meet policy makers' sustainability objectives?', *Journal of Transport Geography*, 13(1), 71-81.

Arencibia, A. I., Feo-Valero, M., García-Menéndez, L. and Román, C. (2015) 'Modelling mode choice for freight transport using advanced choice experiments', *Transportation Research Part A: Policy and Practice*, 75, 252-267.

Beltran, M., Chorus, C., Tavasszy, L. and van Wee, B. (2012) *Preferences relating to container transportation from the port of Rotterdam to the hinterland: Results from a choice experiment*, Delft, The Netherlands: Delft University of Technology.

Ben-Akiva, M. E. and Lerman, S. R. (1985) *Discrete choice analysis: theory and application to travel demand*, Massachusetts, USA: MIT press.

Bergantino, A. and Bolis, S. (2008) 'Monetary values of transport service attributes: land versus maritime ro-ro transport. An application using adaptive stated preferences', *Maritime Policy and Management*, 35(2), 159–174.

Beuthe, M., Bouffioux, C., De Maeyer, J., Santamaria, G., Vandresse, M., Vandaele, E. and Witlox, F. (2005) *A multi-criteria methodology for stated preferences among freight transport alternatives*, In *Methods and models in transport and telecommunications* (pp. 163-179), Berlin, Germany:.Springer.

Blauwens, G., Vandaele, N., Van de Voorde, E., Vernimmen, B. and Witlox, F. (2006) 'Towards a modal shift in freight transport? A business logistics analysis of some policy measures', *Transport Reviews*, 26(2), 239-251.

Bolis, S, and Maggi, R. (2003) ‘Logistics strategy and transport service choices: an adaptive stated preference experiment’, *Growth and Change*, 34(4), 490-504.
Bouffioux, C., Beuthe, M. and Pauwels, T. (2006) ‘La Qualité des Services de Transport de Marchandises: Une Analyse Agrégée des Ordres de Préférences Déclarés’, *Les Cahiers Scientifiques du Transport*, 50, 135-138.
Brooks, M. R., Puckett, S. M., Hensher, D. A. and Sammons, A. (2012) ‘Understanding mode choice decisions: A study of Australian freight shippers’, *Maritime Economics & Logistics*, 14(3), 274-299.
Caris, A., Macharis, C. and Janssens, G. K. (2008) ‘Planning problems in intermodal freight transport: accomplishments and prospects’, *Transportation Planning and Technology*, 31(3), 277-302.
Centobelli, P., Cerchione, R. and Esposito, E. (2017) ‘Environmental sustainability in the service industry of transportation and logistics service providers: Systematic literature review and research directions’, *Transportation Research Part D: Transport and Environment*, 53, 454-470.
Chitsaz, N. and Azarnivand, A. (2017) ‘Water Scarcity Management in Arid Regions Based on an Extended Multiple Criteria Technique’, *Water Resources Management*, 31(1), 233–250.
Combes, F. (2012) ‘An empirical evaluation of the EOQ model of choice of shipment size in freight transport’, *Transportation Research Record - Journal of the TRB*, 2269(1), 92-98.
Cook, P. D., Das, S., Aeppli, A. and Martland, C. (1999) ‘Key factors in road-rail mode choice in India: applying the logistics cost approach’, *Simulation Conference Proceedings*, 2, 1280-1286.
Cullinane, K. and Toy, N. (2000) ‘Identifying influential attributes in freight route/mode choice decisions: a content analysis’, *Transportation Research Part E: Logistics and Transportation Review*, 36(1), 41-53.
Dalla Chiara, B., Deflorio, F. P. and Spione, D. (2008) ‘The rolling road between the Italian and French Alps: modeling the modal split’, *Transportation Research Part E: Logistics and Transportation Review*, 44(6), 1162-1174.
Danielis, R. and Marcucci, E. (2007) ‘Attribute cut-offs in freight service selection’, *Transportation Research Part E: Logistics and Transportation Review*, 43(5), 506-515.
Danielis, R., Marcucci, E. and Rotaris, L. (2005) ‘Logistics managers’ stated preferences for freight service attributes’, *Transportation Research Part E: Logistics and Transportation Review*, 41(3), 201-215.
Day, G. S. (1994) ‘The capabilities of market-driven organizations’, *Journal of Marketing*, 58(4), 37-52.
De Jong, G., Kouwenhoven, M., Bates, J., Koster, P., Verhoef, E., Tavasszy, L. and Warffemius, P. (2014) ‘New SP-values of time and reliability for freight transport in the Netherlands’, *Transportation Research Part E: Logistics and Transportation Review*, 64, 71-87.
Eurostat (2017). Freight transport statistics - modal split, Retrieved on 18-06-2017 from http://ec.europa.eu/eurostat/statistics-explained/index.php/Freight_transport_statistics_modal_split.
Feo-Valero, M., Espino, R. and Garcia-Menendez, L. (2011c) ‘A stated preference analysis of Spanish freight forwarders modal choice on the south-west Europe Motorway of the Sea’, *Transport Policy*, 18(1), 60-67.
Feo-Valero, M., García-Menéndez, L. and Saz-Salazar, S.D. (2016) ‘Rail freight transport and demand requirements: an analysis of attribute cut-offs through a stated preference experiment’, *Transportation*, 43(1), 101-122.
Feo-Valero, M., García-Menéndez, L. and Garrido-Hidalgo, R. (2011a) ‘Valuing freight transport time using transport demand modelling: A bibliographical review’, *Transport Reviews*, 31(5), 625-651.
Feo-Valero, M., Garcia-Menendez, L., Saez-Carramolino, L. and Furio-Prunonosa, S. (2011b) ‘The importance of the inland leg of containerised maritime shipments: An analysis of modal choice determinants in Spain’, *Transportation Research Part E: Logistics and Transportation Review*, 47(4), 446-460.
Fries, H. (2009) *Market potential and value of sustainable freight transport chains*, Zurich, Switzerland: ETH Zurich.
Fries, N. and Patterson, Z. (2008) ‘Carrier or mode?- the dilemma of shippers’ choice in freight modelling’, *Swiss Transport Research Conference*, Ascona, Switzerland.
Fries, N., Nash, A., Wichser, J., Abay, G., Moreni, G. and AG, R. T. (2008) ‘Modal split functions for a Swiss national freight transport model’, *European Transport Conference*, Noordwijkerhout, The Netherlands, 1-17.
García-Menéndez, L. and Feo-Valero, M. (2009) ‘European Common Transport Policy and Short-Sea Shipping: Empirical Evidence Based on Modal Choice Models’, *Transport Reviews*, 29(2), 239-259.
García-Menéndez, L., Martínez-Zarzoso, I. and De Miguel, D. P. (2004) ‘Determinants of mode choice between road and shipping for freight transport: Evidence for four Spanish exporting sectors’, *Journal of Transport Economics and Policy*, 38(3), 447-466.
Greco, S., Figueira, J. and Ehrgott, M. (2005) *Multiple criteria decision analysis*. London, UK: Springer's International Series.
Grue, B. and Ludvigsen, J. (2006) ‘Decision factors underlying transport mode choice in international European freight transport’, *European Transport Conference*, Strasbourg, France, 1-23.
Gupta, H. (2018) ‘Evaluating service quality of airline industry using hybrid best worst method and VIKOR’, *Journal of Air Transport Management*, 68, 35-47.
Gupta, H. and Barua, M. K. (2018) ‘A novel hybrid multi-criteria method for supplier selection among SMEs on the basis of innovation ability’, *International Journal of Logistics Research and Applications*, 21(3), 201-223.

Gupta, H. and Barua, M. K. (2016) ‘Identifying enablers of technological innovation for Indian MSMEs using best–worst multi criteria decision making method’, *Technological Forecasting and Social Change*, 107, 69-79.

Gupta, H. and Barua, M. K. (2017) ‘Supplier selection among SMEs on the basis of their green innovation ability using BWM and fuzzy TOPSIS’, *Journal of Cleaner Production*, 152, 242-258.

Haeri, S. A. S. and Rezaei, J. (2019) ‘A grey-based green supplier selection model for uncertain environments’, *Journal of cleaner production*, 221, 768-784.

Jeffs, V. P. and Hills, P. J. (1990) ‘Determinants of modal choice in freight transport – a case study’, *Transportation*, 17(1), 29-47.

Kheybari, S., Kazemi, M. and Rezaei, J. (2019a) ‘Bioethanol facility location selection using best-worst method’, *Applied energy*, 242, 612-623.

Kheybari, S., Rezaie, F. M. and Rezaei, J. (2019b) ‘Measuring the Importance of Decision-Making Criteria in Biofuel Production Technology Selection’, *IEEE Transactions on Engineering Management*, In press.

Konings, J. W. and Kreutzberger, E. (2001) *Towards a quality leap in intermodal freight transport, theoretical notions and practical perspectives in Europe*. Delft, The Netherlands: Delft University Press.

Lammgård, C. (2007) *Environmental Perspectives on Marketing of Freight Transports, The Intermodal Road-rail Case*, Goteborg, Sweden: BAS Publishing.

Larranaga, A. M., Arellana, J. and Senna, L. A. (2017) ‘Encouraging intermodality: A stated preference analysis of freight mode choice in Rio Grande do Sul’, *Transportation Research Part A: Policy and Practice*, 102, 202-211.

Liang, F., Brunelli, M. and Rezaei, J. (2019) ‘Consistency Issues in the Best Worst Method: Measurements and Thresholds’, *Omega*, 102175.

Macharis, C., De Witte, A. and Ampe, J. (2009) ‘The multi-actor, multi-criteria analysis methodology (MAMCA) for the evaluation of transport projects: Theory and practice’, *Journal of Advanced Transportation*, 43(2), 183-202.

Marcucci, E. and Scaccia, L. (2004) ‘Mode choice models with attribute cutoffs analysis: the case of freight transport in the Marche region’, *European Transport*, 25, 21–32.

Massiani, J., Danielis, R. and Marcucci, E. (2007) ‘The heterogeneity in shipper’s value of time, results from an SP experiment using mixed logit and latent class’, *Pomorstvo*, 21(2)-69-94.

McFadden, D. (1973) *Conditional logit analysis of qualitative choice behavior’, in: Frontiers in Econometrics*, Berkeley, USA: University of California Press.

Meixell, M. J. and Norbis, M. (2008) ‘A review of the transportation mode choice and carrier selection literature’, *The International Journal of Logistics Management*, 19(2), 183-211.

Moktadir, M. A., Ahmadi, H. B., Sultana, R., Liou, J. J. and Rezaei, J. (2020) ‘Circular economy practices in the leather industry: A practical step towards sustainable development’, *Journal of Cleaner Production*, 251, 119737.

Norojono, O. and Young, W. (2003) ‘A Stated preference freight mode choice model’, *Transportation Planning and Technology*, 26(2), 195–212.

Peterson, M. (2009) *An Introduction to Decision Theory*, Cambridge, UK: Cambridge University Press.

Platz, T. (2008) ‘Market perspectives for inland waterway shipping in intra-European intermodal transport’, *European Transport Conference*, Noordwijkerhout, The Netherlands 18-36.

Punakivi, M. and Hinkka, V. (2006) ‘Selection criteria of transportation mode: a case study in four Finnish industry sectors’, *Transport Reviews*, 26(2), 207–219.

Quandt, R. E. and Baumol, W. J. (1966) ‘The demand for abstract transport modes: theory and measurement’, *Journal of Regional Science*, 6(2), 13-26.

Regmi, M. B. and Hanaoka, S. (2015) ‘Assessment of Modal Shift and Emissions along a Freight Transport Corridor Between Laos and Thailand’, *International Journal of Sustainable Transportation*, 9(3), 192-202.

Ren, J. (2018) ‘Technology selection for ballast water treatment by multi-stakeholders: A multi-attribute decision analysis approach based on the combined weights and extension theory’, *Chemosphere*, 191, 747-760.

Ren, J., Liang, H. and Chan, F. T. (2017) ‘Urban sewage sludge, sustainability, and transition for Eco-City: Multi-criteria sustainability assessment of technologies based on best-worst method’, *Technological Forecasting and Social Change*, 116, 29-39.

Rezaei, J. (2015) ‘Best-Worst Multi-Criteria Decision-Making Method’, *Omega*, 53, 49–57.

Rezaei, J. (2016) ‘Best-worst multi-criteria decision-making method: Some properties and a linear model’, *Omega*, 64, 126-130.

Rezaei, J. and Fallah Lajimi, H. (2019) ‘Segmenting supplies and suppliers: bringing together the purchasing portfolio matrix and the supplier potential matrix’, *International Journal of Logistics Research and Applications*, 22(4), 419-436.

Rezaei, J., Hemmes, A. and Tavasszy, L. (2017) ‘Multi-criteria decision-making for complex bundling configurations in surface transportation of air freight’, *Journal of Air Transport Management*, 61, 95-105.

Rezaei, J., Nispeling, T., Sarkis, J. and Tavasszy, L. (2016) ‘A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method’, *Journal of Cleaner Production*, 135, 577-588.

Rezaei, J., Ortt, R. and Scholten, V. (2012) 'Measuring entrepreneurship: Expert-based vs. data-based methodologies', *Expert Systems with Applications*, 39(4), 4063-4074.

Rezaei, J., Wang, J. and Tavasszy, L. (2015) 'Linking supplier development to supplier segmentation using Best Worst Method', *Expert Systems With Applications*, 42(23), 9152-9164.

Rodrigo, M. A. and Ukkusuri, S. V., (2014) 'Attributes driving the selection of trucking services and the quantification of the shipper's willingness to pay.' *Transportation Research Part E: Logistics and Transportation Review*, 71, 142-158.

Salimi, N. (2017) 'Quality assessment of scientific outputs using the BWM', *Scientometrics*, 112(1), 195-213.

Salimi, N. and Rezaei, J. (2018) 'Evaluating firms' R&D performance using best worst method', *Evaluation and Program Planning*, 66, 147-155.

Shinghal, N. and Fowkes, T. (2002) 'Freight mode choice and adaptive stated preferences' *Transportation Research Part E: Logistics and Transportation Review*, 38, 367-378.

Simongáti, G. (2010) 'Multi-criteria decision making support tool for freight integrators: Selecting the most sustainable alternative', *Transport*, 25,1, 89-97

Torabi, S. A., Giahi, R. and Sahebjamnia, N. (2016) 'An enhanced risk assessment framework for business continuity management systems', *Safety science*, 89, 201-218.

Triantaphyllou, E. (2000) *Multi-criteria decision making methods: A Comparative Study*, Boston, USA: Springer.

Tuzkaya, U. R. and Önüt, S. (2008) 'A fuzzy analytic network process based approach to transportation-mode selection between Turkey and Germany: A case study', *Information Sciences*, 178(15), 3133-3146.

van de Kaa, G., Kamp, L. and Rezaei, J. (2017) 'Selection of biomass thermochemical conversion technology in the Netherlands: A best worst method approach', *Journal of Cleaner Production*, 166, 32-39.

van de Kaa, G., Scholten, D., Rezaei, J. and Milchram, C. (2017) 'The Battle between Battery and Fuel Cell Powered Electric Vehicles: A BWM Approach', *Energies*, 10(11), 1707.

Vannieuwenhuyse, B., Gelders, L. and Pintelon, L. (2003) 'An online decision support system for transportation mode choice', *Logistics Information Management*, 16(2), 125 – 133.

Wan Ahmad, N. K. W., Rezaei, J., Sadaghiani, S. and Tavasszy, L. A. (2017) 'Evaluation of the external forces affecting the sustainability of oil and gas supply chain using Best Worst Method'. *Journal of Cleaner Production*, 153, 242–252.

Wanders, G. (2014) *Determining shippers' attribute preference for container transport on the Rotterdam – Venlo corridor*, Master's Thesis, Delft, The Netherlands: Delft University of Technology.

Witlox, F. and Vandaele, E. (2005) 'Determining the Monetary Value of Quality Attributes in Freight Transportation Using a Stated Preference Approach', *Transportation Planning and Technology*, 28(2), 77-92.

Zhang, A., Boardman, A., Gillen, D. and Waters II, W. (2005) *Towards estimating the Social and Environmental Costs of Transportation in Canada*, Vancouver, Canada: Center for Transport Studies, The University of British Colombia.

Zotti, J. and Danielis, R. (2004) 'Freight transport demand in the mechanics' sector of Friuli Venezia Giulia: the choice between intermodal and road transport', *European Transport*, 25-26, 9-20.