Importance of freight mode choice criteria: An MCDA approach

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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
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 CO2 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

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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

<table>
<thead>
<tr>
<th>Reference</th>
<th>Target population</th>
<th>Considered modal alternatives</th>
<th>Method</th>
<th>Door-to-door travel time</th>
<th>Transportation cost</th>
<th>On-time Reliability</th>
<th>Frequency</th>
<th>Flexibility</th>
<th>Loss &amp; damage</th>
<th>CO2-emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shinghal and Fowkes (2002)</td>
<td>Indian firms from six different product sectors</td>
<td>Road, intermodal, and rail transportation</td>
<td>Logit model</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vannieuwenhuyse et al. (2003)</td>
<td>Flemish shippers and logistics service providers</td>
<td>Road, inland, and rail transport</td>
<td>An interactive Internet tool</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Beuthe et al. (2005)</td>
<td>Belgian shippers</td>
<td>Rail, road, waterways, short-sea shipping and their combinations</td>
<td>UTA-UTASTAR</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Zotti and Danielis (2004)</td>
<td>Mechanics companies in the Italian region</td>
<td>Road and intermodal transport</td>
<td>Multinomial logit model</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Punakivi and Hinkka (2006)</td>
<td>Logistics service providers</td>
<td>Ship, road, air, railroad transportation</td>
<td>Qualitative analysis</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bergantino and Bolis (2008)</td>
<td>Italian freight forwarders</td>
<td>Road and maritime ro-ro transport</td>
<td>Tobit Maximum Likelihood</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fries and Patterson (2008)</td>
<td>Canadian shipping managers</td>
<td>Road, rail, and intermodal transport</td>
<td>Qualitative analysis</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>García-Menéndez and Feo-Valero (2009)</td>
<td>Spanish exporters and freight forwarders</td>
<td>Short-sea shipping and road transport</td>
<td>Binary logit model</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 freight 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. Garcia-Menéndez and Martinez-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 CO₂ emission as an important criterion deciding the freight transportation mode choice. Most conclude that the importance of CO₂ 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 CO₂ emission was taken into account to a high degree. In a survey of container
transportation in port hinterlands, Beltran et al. (2012) found that CO₂ 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 CO₂ 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 CO₂ emission importance for Dutch shippers and carriers, but these studies have not been published in the scientific literature. The fact that the CO₂ 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, CO₂ 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 CO₂ 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 CO₂ emission the road transportation generates. Hence, decision-makers may want to incorporate CO₂ emission to an increasing degree as an important criterion. Therefore, reduction of CO₂ 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 CO₂ emission. To conclude, this research includes reduction of CO₂ emission 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:

\[
\begin{align*}
c_1: & \text{ transportation cost;} \\
c_2: & \text{ door - to - door travel time;} \\
c_3: & \text{ on time reliability;} \\
c_4: & \text{ flexibility;} \\
c_5: & \text{ frequency;} \\
c_6: & \text{ reduction of CO}_2 \text{ emission}
\end{align*}
\]

**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>
<thead>
<tr>
<th>Factors</th>
<th>Most Important</th>
<th>Least Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation cost</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Door-to-door travel time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-time reliability</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Flexibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of CO(_2) emission</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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:

\[
A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})
\]

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

<table>
<thead>
<tr>
<th>Factors</th>
<th>Transportation cost</th>
<th>Door-to-door travel time</th>
<th>On-time reliability</th>
<th>Flexibility</th>
<th>Frequency</th>
<th>Reduction of CO2 emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most important</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>9</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

* 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:

\[ A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T \]  

(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

<table>
<thead>
<tr>
<th>Factors</th>
<th>Least important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation cost</td>
<td>7</td>
</tr>
<tr>
<td>Door-to-door travel time</td>
<td>9</td>
</tr>
<tr>
<td>On-time reliability</td>
<td>8</td>
</tr>
<tr>
<td>Flexibility</td>
<td>1</td>
</tr>
<tr>
<td>Frequency</td>
<td>5</td>
</tr>
<tr>
<td>Reduction of CO2 emission</td>
<td>3</td>
</tr>
</tbody>
</table>

* 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 \((w_1^*, w_2^*, w_3^*, \ldots, w_n^*)\) 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:

\[
\begin{align*}
\min & \max_j \{ |w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W| \} \\
\text{subject to} & \\
\sum_j w_j &= 1 \\
w_j &\geq 0, \text{ for all } j
\end{align*}
\]  

(3)

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

\[
\begin{align*}
\min & \xi^L \\
\text{subject to} & \\
|w_B - a_{Bj}w_j| &\leq \xi^L, \text{ for all } j \\
|w_j - a_{jW}w_W| &\leq \xi^L, \text{ for all } j \\
\sum_j w_j &= 1 \\
w_j &\geq 0, \text{ for all }
\end{align*}
\]  

(4)

Solving problem (4) provides a unique set of optimal weights \((w_1^*, w_2^*, w_3^*, \ldots, w_n^*)\) and \( \xi^{L^*} \). \( \xi^{L^*} \) is an indicator of the consistency of the comparison system, and the closer the value of \( \xi^{L^*} \) 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 CO₂ 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 ($\xi^L$). 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 $\xi^L$ to zero the more reliable the results are.

Table 5. Mean weights and standard deviation of criteria

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

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; Daniilis 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 Cullinan 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.
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.

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

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

* 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

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

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

*p < 0.05 shows significant difference between the two corresponding groups
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 CO2 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 CO2 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 CO2 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 CO2 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

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