

TRANSPORT FINDINGS

Multigroup Multimodality Index: A Method to Solve the Issue of Transport Mode Classification in Measuring Multimodality

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Findings

Recent methods to measure multimodality only consider the diversity and evenness of mode use, while ignoring that the classification of transport modes also matters. This study proposes a multigroup multimodality index to measure the extent of being multimodal at both single mode and mode group levels in a nested manner. The index is compared with the two most commonly used indices, the Herfindahl-Hirschman index and the Shannon Entropy index, to assess its reliability and improvement over existing approaches. Results show that the multigroup multimodality index can simultaneously distinguish the degree of being multimodal at both mode level and group level, which addresses the classification issue in measuring multimodality.

1. Questions

Multimodality has the potential to alleviate environmental problems and inequality resulting from car dependency. Multimodality is often defined as an individual's use of multiple transport modes for travel within a certain time period. Though the concept of multimodality is considerably uniform, methods to measure multimodality are still sub-optimal.

Previous studies have mainly considered two aspects to evaluate the variability of an individual's transport mode use, diversity and evenness. Diversity is usually measured by the number of transport modes used, and evenness is usually measured by the relative intensity of use of each mode. To capture both dimensions, studies used continuous indices from different disciplines to measure the degree of multimodality (see: [Appendix 1](#)), ranging from welfare economics (Gini, Dalton and Atkinson indices) to information theory and ecology (entropy, Herfindahl index) (Astroza et al. 2017; Diana and Pirra 2016).

A crucial, but mostly overlooked aspect that determines the outcome of multimodality measures is the classification of transport modes. Consider the example of bus, tram and metro, which are all public transport modes. If we consider them as one single mode, the multimodality of people using all three modes will be underestimated. If we consider them as three separate modes, the difference between the three public transport modes is regarded as similar to the difference between any of them and for instance car. This leads to an overestimation of multimodality for people only using the three public transport modes, if we regard combinations of public transport modes and private modes as being more multimodal than combinations of public transport modes only.

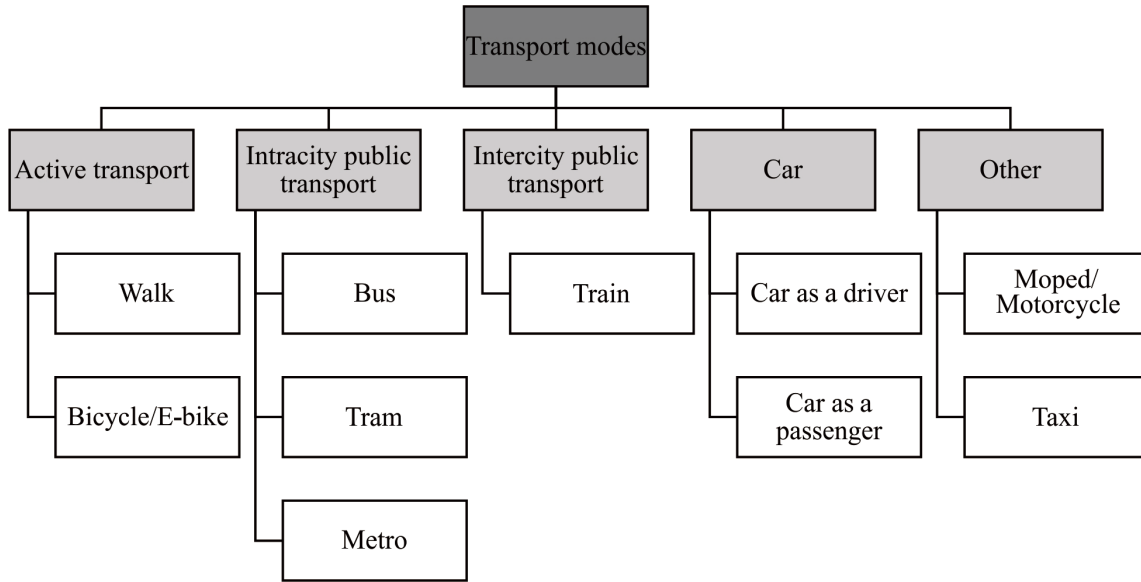


Figure 1. Classification of transport modes at two levels

To account for differences in similarity between transport modes, this paper proposes a multigroup multimodality index to measure the extent of being multimodal at both aggregate and segment levels. The index is demonstrated using a dataset collected in Utrecht and Rotterdam in the Netherlands.

2. Methods

The data used in this study is from a survey conducted in the summer of 2021 in Rotterdam and Utrecht, two major cities in the Netherlands. In this survey, the frequency of use of 13 different transport modes over the past year is recorded based on a seven-level scale, from ‘almost never’ to ‘almost daily’. The valid sample of this analysis contains 1009 participants.

First, we aggregate transport modes into groups based on three criteria: 1) similarity or substitutability of transport modes, 2) the usage of transport modes in the Netherlands, and 3) the classification of transport modes in previous studies (see: [Appendix 2](#)). Since few people use regiotaxis (a form of demand responsive transport), cargo bikes or scooters in our sample, we first ruled out these three modes and then grouped the remaining ten modes into five groups. Since mopeds/motorcycles and taxis are both motorised modes that are only used by small groups of people, we put them in the “other” group.

Second, we define the multigroup multimodality index. This index is based on multigroup entropy measures used to measure regional ethnicity diversity in the field of social ecology (Reardon and Firebaugh 2002). To define multigroup multimodality, we modify the Shannon entropy index to arrive at a nested entropy index:

$$MMI = \sum_{g=1}^G \left\{ p_g \left(\log_G \frac{1}{p_g} \right) \sum_{i=1}^n \left[p_{ig} \left(1 + \log_n \frac{1}{p_{ig}} \right) \right] \right\}$$

Where

$$p_g = \frac{\max(f_{ig})}{\sum_{g=1}^G \max(f_{ig})}$$

$$p_{ig} = \frac{f_{ig}}{\sum_{j=1}^n f_{jg}}$$

G refers to the number of groups, n refers to the number of transport modes in Group g , and f refers to the frequency of use of Mode i in Group g . If p_g or p_{ig} equals to 0, $\log_G \frac{1}{p_g}$ or $\log_n \frac{1}{p_{ig}}$ is converted to 0. The inner nest of the equation $\sum_{i=1}^n \left[p_{ig} \left(1 + \log_n \frac{1}{p_{ig}} \right) \right]$ is a modified Shannon entropy index that measures the diversity and evenness of mode use within a mode category. The outer nest of the equation further used the form of the Shannon entropy index to measure the diversity and evenness of mode use among different categories, while using the inner nest scores as weights. Thus, in a nested form, the defined index simultaneously measures the variability of mode use within a category and across categories.

Third, we convert the frequency class of mode use from the seven-level scale (namely, ‘almost daily’, ‘a few times a week’, ‘once a week’, ‘a few times a month’, ‘once a month’, ‘a few times per year’, ‘almost never’) to absolute yearly frequencies as follows: 365, 180, 52, 30, 12, 5, 0.

The index has a minimum value of 0 when an individual uses transport modes from only one single group. The maximum of the index depends on the number of groups and the number of transport modes in each group. If there are G groups in total, of which x groups contain only one transport mode, and the remaining $(G-x)$ groups contain more than one, then the maximum of the index is $[x+2(G-x)]/G=2-x/G$. Thus, the range of the index is $[0, 2-x/G]$. In this case, there are 5 groups of transport modes, with 1 group containing only one mode and 4 groups containing two or more modes. The index has a maximum of 1.8 when an individual uses all modes in all groups with the same frequency.

To assess the reliability and improvement of Multigroup Multimodality Index, we compare the scores calculated by this index with the results measured by Herfindahl-Hirschman index (HHI) and Shannon Entropy (OM_PI), which are two most commonly used indices in previous studies. Equations of these two indices are:

$$HHI = \frac{1}{n} \left[\frac{n \sum_{i=1}^n (f_i - \bar{f})^2}{(\sum_{i=1}^n f_i)^2} + 1 \right]$$

$$OM_PI = \sum_{i=1}^n \left[\frac{f_i}{\sum_{j=1}^n f_j} \log_n \left(\frac{\sum_{j=1}^n f_j}{f_i} \right) \right]$$

Where n refers to the total number of modes in the choice set, f_i refers to the intensity of use of the i^{th} mode, and $\bar{f}$ refers to the mean value of the intensities of all n modes considered. The range of HHI is $1/n$ to 1, with $1/n$ means equally use all modes and 1 means only use one mode. The range of OM_PI is 0 to 1, while 0 means only use one mode and 1 means equally use all modes. To better compare the three indices, we standardise and invert HHI as well as standardise MMI to make them in the same range and order with a minimum level of multimodality at 0 and maximum level at 1.

$$sHHI = 1 - \frac{HHI - \frac{1}{n}}{1 - \frac{1}{n}}$$

$$sMMI = \frac{MMI}{\max(MMI)}$$

3. Findings

[Figure 2](#) presents the distributions of scores calculated by the three indices. On the whole, the distributions of all three indices are bell-shaped. The distributions of OM_PI and MMI are similar, while the scores of MMI are generally smaller than that of OM_PI . This is because MMI is measured in a nested manner, using multiple modes within a group results in a higher score for this nest, but a lower overall score due to the unevenness between groups. The distribution of HHI is more skewed and concentrated in the high-value area. Since HHI and OM_PI both measure multimodality at the mode level (ignoring the similarity between modes), they regard the difference between modes from different groups as similar to the difference between modes from the same group, so these two indices tend to overestimate multimodality.

[Figure 3](#) presents the relationship between the scores of each index and the number of modes and groups. Of these three indices, only MMI shows gradient differences in both the number of modes and the number of groups.

When the number of groups is the same, scores for all three indices increase with the number of modes, which is expected since all indices measure multimodality at the mode level. However, the score of HHI does not increase evenly when the number of modes increases by the same unit.

With the same number of modes used, the scores of HHI and OM_PI do not show significant differences when the numbers of groups are different. In certain cases, using more groups even results in a lower score of multimodality (e.g. when the number of modes is 4, scores of HHI and OM_PI with 2 groups are even higher than the scores with 3 or 4 groups). By contrast, MMI does distinguish scores at different group levels: in most cases, with the same number of modes used, the higher the number of groups, the higher the score

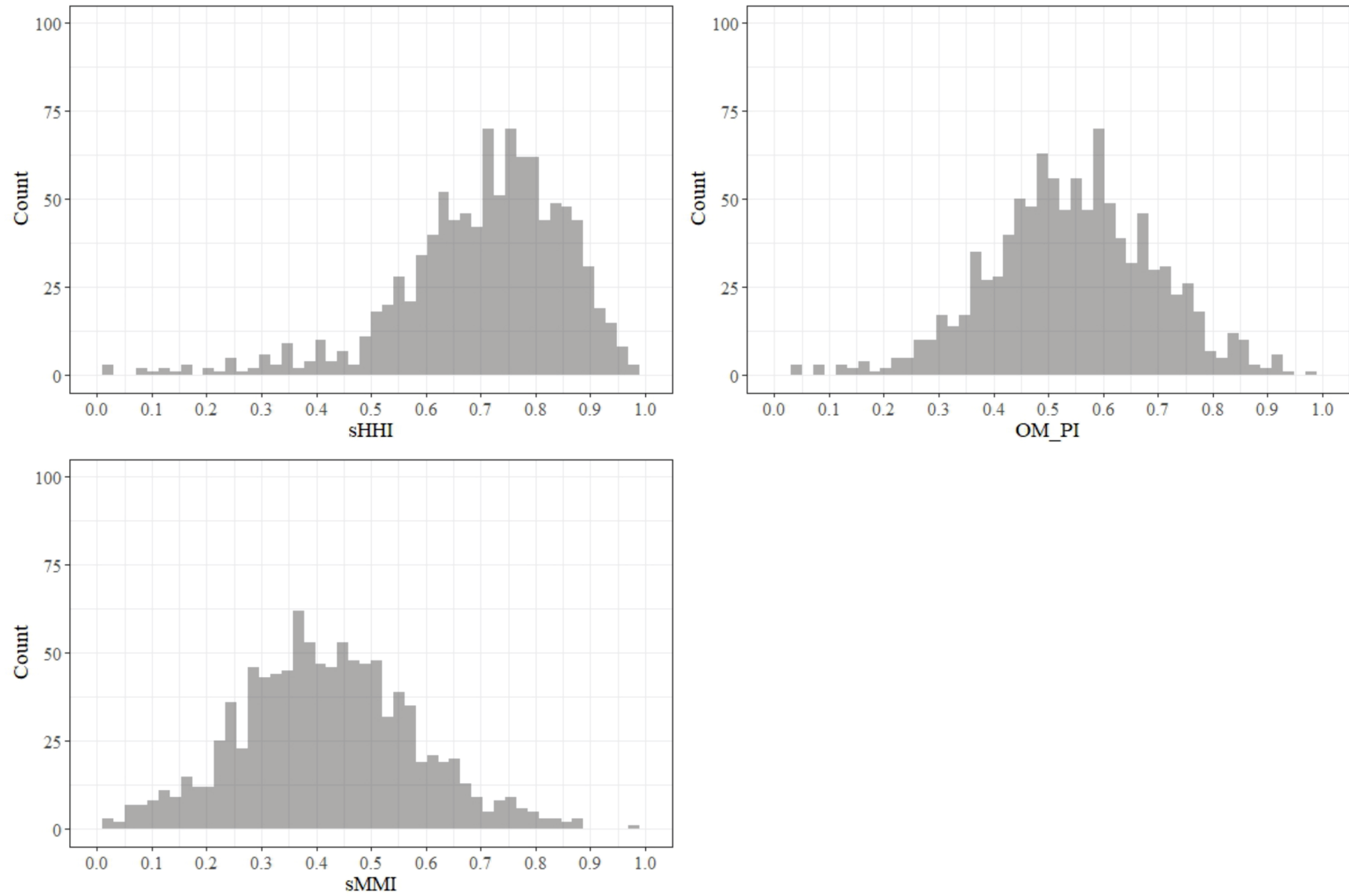


Figure 2. Distributions of scores calculated by HHI, OM_PI and MMI

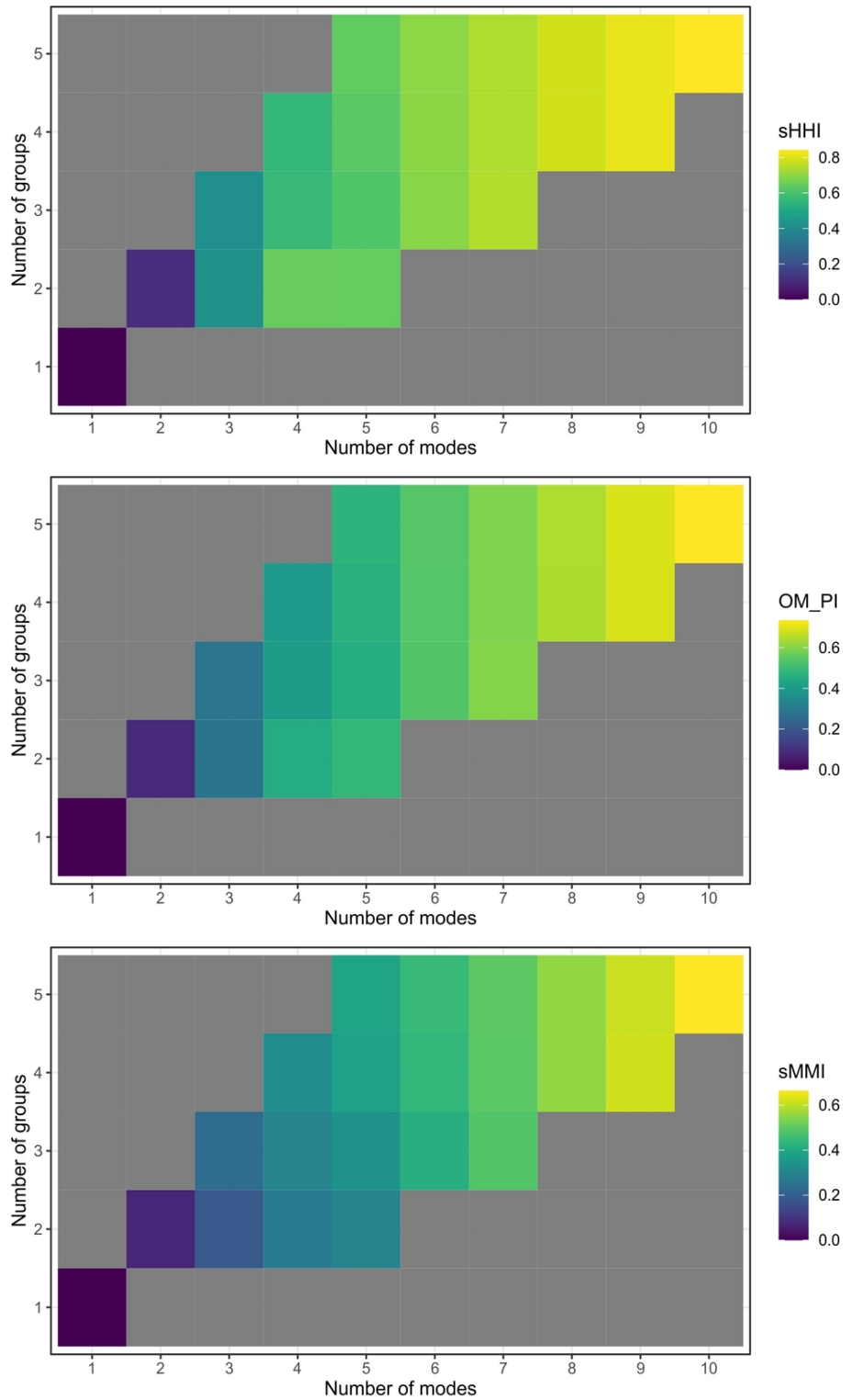


Figure 3. The relationship between the scores and the number of modes and groups

of multimodality. Nevertheless, due to the limited sample, and the degree of multimodality is also measured by the evenness of frequency, a few cases in the figure do not strictly meet the aforementioned description.

The findings show that the multigroup multimodality index can distinguish the degree of multimodality at both the mode level and group level. This solves the issue of the classification of transport modes in the measure of

multimodality to a certain degree. Thus, in future research on multimodality, we can define the classification of travel modes depending on the problem under consideration and apply this index. Moreover, this index may also be applied in other research on diversity or variability, such as land use mix, and space-time flexibility of daily activities.

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Appendices

Appendix 1. Indices used to measure multimodality in previous studies

Index	Reference measures	Equation	Range
GI	Gini index	$GI = \frac{2}{n} \frac{\sum_{i=1}^n i \cdot f_i}{\sum_{i=1}^n f_i} - \frac{n+1}{n}$	[0, 1]
HH	Herfindahl index	$HH = \frac{1}{n} \left[\frac{n \sum_{i=1}^n (f_i - \bar{f})^2}{(\sum_{i=1}^n f_i)^2} + 1 \right]$	[1/n, 1]
HH _m	Herfindahl index (m)	$HH_m = \frac{1}{m} \left[\frac{n \sum_{i=1}^n (f_i - \bar{f})^2}{(\sum_{i=1}^n f_i)^2} + 1 \right]$	[1/m, 1]
OM _{PI}	Shannon entropy	$OM_{PI} = \sum_{i=1}^n \left[\frac{f_i}{\sum_{j=1}^n f_j} \log_n \left(\frac{\sum_{j=1}^n f_j}{f_i} \right) \right]$	[0, 1]
OM _{MI}	Shannon entropy (M)	$OM_{MI} = \sum_{i=1}^N \left\{ \frac{f_i}{nM} \left[1 + \ln \left(\frac{M}{f_i} \right) \right] \right\}$	[0, 1]
TH	Theil index	$TH = \frac{1}{n} \sum_{i=1}^n \frac{f_i}{\bar{f}} \ln \left(\frac{f_i}{\bar{f}} \right)$	[0, ln n]
DAL	Dalton index	$DAL = 1 - \frac{\frac{1}{n} \sum_{i=1}^n (f_i^{1-\varepsilon} - 1)}{\bar{f}^{1-\varepsilon} - 1}$	$[0, (1 - n^{-\varepsilon}) / (1 - (f/n)^{\varepsilon-1})]$
DAL _m	Dalton index (m)	$DAL_m = 1 - \frac{\frac{1}{n} \sum_{i=1}^m (f_i^{1-\varepsilon} - 1)}{(\frac{1}{m} \sum_{i=1}^m f_i)^{1-\varepsilon} - 1}$	[0, (n-1)/n]
ATK	Atkinson index	$ATK = 1 - \left[\frac{1}{n} \sum_{i=1}^n \left(\frac{f_i}{\bar{f}} \right)^{1-\varepsilon} \right]^{\frac{1}{(1-\varepsilon)}}$	$[0, 1 - n^{-\varepsilon/(1-\varepsilon)}]$

n: the total number of modes in the choice set

f_i : the intensity of use of i^{th} mode (for GI, the data ordered by increasing size of elements)

$\bar{f}$: the mean value of the intensities of all n modes considered

m: the m elements different from zero (the number of modes actually used)

M: the absolute maximum reported frequency of utilization of any mode across all observations in the sample

ε : a setting parameter

Appendix 2. Classification of transport modes in previous studies

Author	Country	Transport modes categorization
Kuhnimhof, Chlond, and Von Der Ruhren (2006); Kuhnimhof, Wirtz, and Manz (2012)	Germany	Walk, bicycle, car (driver), car (passenger), public transport, train
Nobis (2007)	Germany	Car, bicycle, public transport
Diana (2012); Diana and Mokhtarian (2008); Diana and Mokhtarian (2009a, 2009b); Diana and Pirra (2016)	the USA, France	Bicycle, motorcycle, car (driver), car (passenger), bus, tram, metro, taxi, suburban train, long-distance train,
		Personal vehicle, bus, train/light rail, walk/jogging/cycling
Buehler and Hamre (2013)	the USA	Walk, bicycle, car, public transport
Kroesen (2014)	Netherlands	Car, public transport (bus, tram, metro, train), bicycle
Buehler and Hamre (2015)	the USA	Walk, bicycle, public transport, car (driver and passenger)
Heinen and Chatterjee (2015)	the UK	Walk, bicycle, car (driver), car (passenger), bus, rail, taxi, other (motorcycle, other private and other public)
Streit et al. (2015)	the USA	Walk, bicycle, public transport, car (driver and passenger)
Buehler and Hamre (2015)	the USA	Car (driver), public transport, walk, bicycle
Molin, Mokhtarian, and Kroesen (2016)	Netherlands	Car, bicycle, train, public transport (bus, metro, train)
Astroza et al. (2017)	the USA	Car (driver and passenger), public transport, bicycle (personal and sharing), walking, carsharing, ride-sourcing
Klinger (2017)	Germany	Car, bicycle, public transport, walk
Rodriguez Cote and Diana (2017)	France	Bicycle, motorcycle, car driving, car passenger, bus, tram, metro, taxi, suburban train, long-distance train
Heinen (2018)	the UK	Car, bicycle, walk, public transport
Circella, Lee, and Alemi (2019)	the USA	Driving, carpooling, public transport, active modes
Heinen and Mattioli (2019a, 2019b)	the UK	Car (driver and passenger), active modes (walk, bicycle), public transport (bus, rail, taxi and other)
		Walk, bicycle, car (driver), car (passenger), bus, rail, taxi, other (motorcycle, other private and other public)
Thomas, La Paix Puello, and Geurs (2019)	Netherlands	Active modes, car, public transport, other
Tsirimpa et al. (2019)	the UK, Austria	Public transport (bus, tram, train), bicycle, bicycle sharing, walking, car sharing, car, car pooling
Faber et al. (2020)	Netherlands	Car, train, public transport (bus, tram, metro), bicycle
Lee et al. (2020)	the USA	Car (driver and passenger, including taxi and ride-hailing), public transport (bus, rail), active modes (walk, bicycle, skateboard), emerging transport modes (ride sourcing and carsharing)
An, Heinen, and Watling (2021)	the UK	Walk, bicycle, car (driver), car (passenger), bus, railway, taxi, other
Deschaintres, Morency, and Trépanier (2021)	Germany	Car (driver and passenger), subway, bus, school bus, train, taxi, bicycle, walk, paratransit, other modes (including intercity modes)
Lehtonen et al. (2021)	8 EU countries	Walk, private personal bicycle, shared bicycle, motorcycle, private car (driver), shared car (driver), car (passenger), short-distance public transport, long-distance public transport