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Incorporating Latent Variables into Active Transportation Mode Choice: A review

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ABSTRACT

Active transportation mode is highly recommended for achieving sustainable requirements. Studying the factors and strategies that promote these modes of transportation has been the focus of recent research. The most common factors are objective factors, such as travel cost and time, that can be quantified. Recently, there has been an adequate amount of proof that attitudes have a significant impact on mode choice. It is a type of subjective factor that cannot be quantified. The latent variables have been used to represent attitude in the mode choice models and travel behavior studies. To what extent do the latent variables affect the mode choice? This was the aim of many researchers. To get the right answer, they have studied how to incorporate the latent variables into mode choice models and what variables have the most influence on the mode choice. the aim of this research is to review the latent variables that have been investigated in the previous studies of active transportation and the techniques used to incorporate them into the models. The findings showed that latent variables have been incorporated alongside the traditional explanatory variables. The traditional models are not fitted to incorporate attitude into them. Therefore, an extension of the traditional method called integrated choice models and latent variables has been developed, and it's fitting was more significant than the traditional methods. In addition, the extended models are capable of incorporating more variables than the traditional models.

1. Introduction

Growing car usage and ownership have led to major traffic issues and high emission levels of greenhouse gases in the past decade. Individual socioeconomic variables, mode features, and trip characteristics all influence the behavior of conventional transport mode choices [1-3]. Active transportation is the mode of transportation that is highly recommended for achieving sustainable requirements; walking and cycling are examples of active transportation. The ridership of these modes has been studied to promote cycling and walking. On the other hand, there is an adequate amount of proof that attitudes have an important effect on decision-making. There are a variety of distinct factors that have an effect on the utilization of commuting trips; they can be classified into "objective" and "subjective" categories according to the methods of measurement that they employ [4]. Objective factors are variables that can be quantified, while subjective variables could not be quantified, such as the habit or behavior of road users [5-6]. The subjective variables are represented by latent variables (LV). The models that involve the latent variables are called latent models, such as the latent model choice that is linked to a habitual travel mode or combination of modes. People with the same

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objective variables might not select the same mode of transportation due to perception and attitude factors [7-9]. However, the influence of attitudes on mode decision behavior was ignored.

2. Factors Affecting Walking and Cycling Mode Choice

The factors of selecting walking and cycling as a mode of daily transportation activities will be shown in the sections below [10].

2.1 The individual and household characteristics

Individual characteristics are those related to the characteristics of people. Examples of individual characteristics are sex, age, education level, ability to use a mode, ownership, and socio-demographic characteristics. Men often walk and cycle more than females in countries with low cycling use and, in contrast, in countries with high cycling use. However, this could be changed according to other factors such as culture and purpose. Regarding age factors, the highest percentage of cycling is mostly young people. People with higher education levels, especially those who own cars, tend to use motorized vehicles.

2.2 Weather condition

Weather condition is almost one of the influential factors of walking and cycling behavior. Weather conditions in Winter in rainy countries and Summer in hot countries are negatively associated with choosing walking and cycling; especially for longer distance.

2.3 Trip characteristics

Travel distance and travel time are the most investigated factors in previous studies. Both have a negative correlation with walking and cycling. Because travel distance is related to the built environment, its effect is not the same, and it may be based on the purpose of the trip. For recreational purposes, people may walk and cycle for longer distances than for work purposes.

2.4 The built environment characteristics

The built environment represents road infrastructure and the availability of cycling and walking facilities; the availability of cycle paths, bicycle parking, and sidewalks are examples of them. Their availability is positively associated with cycling and walking. Aesthetics are also a factor in active transport modes and have a positive effect on them. It includes the availability of parks and seats, and mixed land use has a positive association with active modes, while areas with low residential density have negative associations. Other factors related to the built environment are also investigated in previous studies, such as the availability of traffic lights and the size of cities.

3 Attitude to general mobility and active transportation

Attitudes can be defined as “Relative assessments that people make of others, objects, or concepts depending on their viewpoint”; it is almost considered as psychological behavior. Sottile et al. [11] stated that attitudes are not only emotive responses to an object that are solely impacted by ideas but also express cognitive aspects and past behaviors regarding an attitude object. For example, the affective aspect of an attitude may encompass feelings of independence, enjoyment, and tranquility, while the cognitive aspect may encompass flexibility, speed, comfort, affordability, and safety. The behavioral component encompasses factors that individuals evaluate when selecting these modes of transportation, such as pollution and social interaction.

Yáñez et al. [12] defined attitudes as the characteristics of individuals about a thing, and they are inherently influencing every action undertaken. It is different from perceptions which are exclusively linked to the way certain decisions are interpreted. In such instances, an attitude parallels a socioeconomic characteristic of the individual, while a perception is basically associated with a discrete option.

Lyu and Forsyth [13] defined attitudes as a positive or negative perspective on a phenomenon, whereas perceptions are beliefs about it. Perceptions and attitudes can influence transportation behavior, such as causing an individual to walk less owing to concerns about crime. Transport activity may also influence perceptions; for instance, a motorist might regard traffic congestion as problematic, whereas a pedestrian may not. Understanding the relationships between attitudes toward each mode of transportation and general perceptions is crucial for informing urban strategies that encourage walking and cycling as viable transit options. It is also essential to formulate effective methods to enhance the utilization of such modes. A positive attitude towards any transportation mode leads to a higher choice of that mode in the condition of no restriction with any other factor. It has been proven in previous studies that a positive attitude towards a certain mode is a determinant of residential location [13,14]. The attitude is not only affecting the mode choice, but also it is affected by the most common mode use and the behavior of travel. For example, increasing the frequency of bus service affect positively the attitudes towards choosing bus mode and it is highly connected with mode shift from car use to public transport use [15]. Thus, enhancing a mode's performance may enhance people's attitude of that mode.

Dill et al. [13] investigated the use of the theory of planned behaviour (TBP) concept in understanding the choice of people, their active transportation modes, and the role of the built environment and demographic characteristics in their choice. A telephone survey of 1159 residents selected randomly in Portland, U.S., was used to collect the needed data. It has been found that walkable environments and demographic characteristics indirectly affect walking behavior through psychological factors, including attitudes toward walking. In addition, they found that improving the non-motorized infrastructure alone, such as cycling lanes, is not a factor in improving walking behavior. Enforcing these infrastructures by improving connectivity, public events, and traffic situations are most likely to produce better walking behavior.

Yang and Diez-Roux [16] studied the interaction between people's attitudes to walking and the built environmental factors and to what extent they affect walking mode choice. Data were collected from a randomly selected sample of 2621 persons from 2011 to 2012 in eight states in the USA. The results showed that there is a strong correlation between walking behavior and walking among those who have a positive attitude toward walking for both transportation and leisure. But there is no correlation when people have a negative attitude toward walking.

Ding et al. [17] examined the effect of attitudes towards walking and cycling on commute mode choice in China through analyzing collected data from a survey of 1110 respondents living close to their workplace, about 5 km or less. Discrete choice model (DCM) and the structural equation model (SEM) were used in analyzing data. They discovered that opting to walk or ride a bike to work was significantly correlated with latent attitude and social characteristics.

Hatamzadeh [18] investigated whether commuters have a positive attitude to walk for transport to/from work in the city of Rasht, Iran. Data was collected through a survey of 432 working commuters and analyzed using an SEM. The findings showed that attitude towards walking is going to be positive as the trip time or the walking distance between work and home is shorter. The findings of this study enhanced the role of attitude in deciding the mode of transportation; improving the attitude will lead to a higher selection of walking trips.

Chan et al. [19] investigated the effect of walking attitudes on the frequency of walking in Shenzhen City in China. Three trip purposes have been considered in this study, which are: walking for work and school, leisure, and household responsibilities. Based on the results of regression analysis of 890 respondents to a self-design survey, it has been demonstrated that there is a significant association between objective and subjective dimensions of the built environment with walking attitudes. For leisure purpose trips, it was shown that walkers might have a positive attitude despite a less walkable built environment, reflecting the positive effect of attitude on walking behaviour in general. However, attitudes toward walking had no significant effect on work and school trips and household responsibilities.

Lyu and Forsyth [13] carried out a study to investigate how Chinese people's attitudes toward using urban mobility and transportation modes relate to their preference for walking as a form of transportation. A wide range of factors are considered in this study to measure the attitude toward them. The selection of the variables was based on their importance from the authors' point of view and filtered using Pearson's bivariate correlation. The transport modes include motorized and non-motorized modes of transportation. The attitude towards the overall transportation convenience, safe crossing streets, and presence of sidewalks have also been investigated. Data was collected from 1048 people through the survey. They were analyzed using descriptive statistics, t-tests, analysis of variance (ANOVA), hierarchical logistic models, and hierarchical linear models. It was found that the positive attitude and perceptions are related to the walking mode choice. They also investigated the effect of the attitude to walking facilities on the walking time. When taking into account the gender factor, it is found that both males and females have been most likely to select walking when they have a positive attitude toward general mobility in terms of bus frequency for males and supplying convenient transportation for females. The findings showed that providing safe pedestrian crossing leads to a positive attitude toward walking even if the walking time is longer. It was also found that the observed traffic jams in the transport networks have a positive correlation with walking time. Therefore, it has been recommended in this study to enhance safer design for intersections and supply them with safe pedestrian facilities to promote walking.

De Vos [20] reviewed the history of incorporating the attitude factor in transportation planning, travel behaviour, and mode choice for various transportation modes. It is mentioned in this review that the first studies that demonstrated the mutual effect of public transport behavior and attitude of people were published at the end of the 1970s. In 1990, the TPB theory was used to predict travel behavior, assuming a stable attitude. The focus of these researches was the effect of attitude towards using private and motorized public transportation. It was concluded that attitudes have an effect on travel behavior when ideal conditions are available and people have the freedom to choose transport modes, but the attitude has been affected by travel behavior and the built environment when choices are not free. A good example is that people who prefer cycling are not able to cycle due to long distances or unsafe environments. Therefore, the relationship has been more complicated, and new advanced methodologies have been developed.

4 The Integrated Choice and Latent Variable (ICLV)

In earlier studies, a variety of techniques were employed to obtain the parameters for the discrete choice and psycho-social models. Psychological elements or indicator variables (such as survey responses on attitudes and perceptions) have been directly incorporated into the utility function by certain researchers. Because indicator variables are dependent on survey question design, are not causative, and can result in multicollinearity, Walker [21] and Ben-Akiva et al. [22] recommended against using them directly in the choice model.

Other researchers employed a developed method that included the latent variables directly in the discrete choice model and then represented them using Exploratory Factorial Analysis (EFA). Using MIMIC (Multiple Indices and Multiple Causes) as the initial step, a third approach integrates the latent variables with the explanatory factors in a discrete choice model. Lastly, alternatives include inclusion with random parameters in a mixed Logit model or integration throughout a range of latent variable variations. The majority of researchers adopt sequential procedures since they are intuitive but do not use all the information at once [23].

The ICLV formulations have been introduced by researchers to allow the choice model to include many latent variables without convergence or estimation time issues. One of the most popular hybrid models and conceptual frameworks for enhancing predictive power and better understanding consumer behavior is the ICLV model, which permits the incorporation of attitudes, beliefs, and perceptions as psychometric latent variables [22,24]. In order to overcome the drawbacks of earlier models that did not accurately represent attitudes, the researchers decided to use the ICLV framework [25]. The measurement model and the structural model are two components. While the second model explains psychological factors using personal characteristics to enhance their effect on latent variables and how they differ from the effect on other factors, the first model explains the relationship between indicators and psychological factors [26].

Developing an ICLV model requires an accurate layout across three dimensions: collecting data, Estimation of the SEM and the DCM, and integrating latent variables into models [27].

4.1 Data collection and sample size

The data collection process must be adjusted to gather indicators that assess the latent variables. Particular care must be given to the sample size, as an increased number of estimated factors may lead to classification challenges. A standard preference survey with questions on the preferences and perceptions of the users is the method used to identify them and produce the attitude indicators [21].

4.2 Estimation of SEM and DCM

The ICLV models involve an estimation of SEM and DCM. In this step, latent variables and their interrelation are examined using SEM. The term "SEM" is deliberately employed to signify the complexity of the models that can be incorporated into the ICLV model and to establish a connection with psychological and management science frameworks. The SEM is an approach for describing, estimating, and evaluating a network of interactions among variables, which may be measurable or latent, as well as exogenous or endogenous. They can depict a diverse range of interactions among variables, specifically mediation and moderation processes [28].

Selecting attitude indicators is the initial stage in measurement model building. The EFA ensures that all selected indicators measure the same factor with substantial factor loadings. Cronbach's alpha is used to verify each construct's internal consistency; values above 0.5 are acceptable [29]. As EFA indicators will be included in SEM models later, a confirmatory factor analysis (CFA) is performed to validate measurement model goodness-of-fit and assure significant factor loadings. CFA and SEM use maximum likelihood estimates (MLE) based on normality; hence, indicators should be evaluated for normality first [5, 30, 31].

The multivariate normalcy test assesses two primary indices, skewness, and kurtosis, and evaluates them based on their absolute values. (1) An absolute value of S above 3.0 indicates extreme skewness; (2) an absolute value of K more than 10.0 signifies an issue with kurtosis; and (3) an absolute value of K beyond 20.0 denotes extreme kurtosis [32].

4.3 Inclusion of latent variables into models

In order to improve the behavioral realism of mode choice models, latent variables are incorporated into the deterministic component of utility. Two primary approaches have been used in prior research to incorporate latent variables into discrete choice models: the sequential method, which uses the MIMIC model to consistently specify latent variables, and the simultaneous estimation approach, which estimates both components of the hybrid model simultaneously.

Depending on the representational utility of the modeler, the simultaneous estimation strategy maximizes the likelihood of reproducing individual decisions. Since LVs are invisible, their whole range of variation must be integrated, subject to the explanatory variables. It must be utilized to estimate the model since it would not be identifiable without perception indicator data. Instead of being explanatory, the indicators are endogenous to LVs. Simulated maximum likelihood can be used to define and estimate the DCM's functional form. Walker [21] advises against this process since these indicators are not causative and may cause problems with multicollinearity.

The parameters that link the latent variable to the explanatory variables and attitude indicators are estimated and standardized using a MIMIC model. The latent variable values for each individual and alternative are then determined using these parameters, and they are subsequently incorporated into the discrete choice model. This methodical approach demonstrates the interplay between the MIMIC and choice models, enabling the LV to function as an explanatory variable [23]. The most often used method is the sequential technique since it is easy to understand and use, but it does not make use of all the information that is accessible.

5 Explanatory and Latent variables

This section presents a review of the explanatory and latent variables used in previous research. Table.1 shows brief of the reviewed literatures. Kamargianni and Polydoropoulou [26] customized a stated preferences survey in Cyprus that was suitable for studying teenage students' behaviors and attitudes. The target alternatives of modes were a car, bus, cycling, and walking. The contributing factors were travel time, cost, availability of cycling paths, sidewalks, parking, and weather conditions. It was found that positive attitude, travel time, and cost have significant roles in choosing active transportation. In addition, the availability of bike paths and parking and wide sidewalks affect the choice of cycling and walking, respectively. Weather conditions also have a significant effect on the mode of transportation.

Paulssen et al. [25] examined the effect of attitude on travel mode choice in German using the ICLV. The investigated explanatory variables were age, income, and number of cars in household. The most influenced latent variables were flexibility, comfort and convenience, and ownership which have not significant effect when they had been included directly. This means that the ICLV produced more fitted models.

Maldonado-Hinarejos et al. [28] conducted an empirical analysis of collected data from the state survey in London to investigate the impact of attitude on the cycling demand. The investigated factors were infrastructure, socio-demographics, attitudes, and perceptions. However, it has been concluded that despite the advantageous capabilities of discrete choice models, a hybrid model has been more manageable. In addition, combining objective indicators, such as infrastructural, demographic, and geographical indicators, and subjective indicators, such as attitudes and perceptions together, led to improving the models' fitting and plausible estimated parameter values.

Kamargianni et al. [24] introduced a novel multinomial probit (MNP)-based ICLV framework to examine teenagers' travel mode selection for school, incorporating safety awareness, environmental consciousness, and inclination towards physical activity. The data utilized in the empirical research derives from a survey conducted in Cyprus in 2012, in which about 124 teenagers participated in the study, each presented with two instances of mode choice for commuting to school. This methodology enabled the integration of three latent variables utilizing a substantial data sample and ten ordinal indicators for the latent variables. The hybrid method was contrasted with the conventional DCM methodology. The novel methodology provided substantial benefits, enabling the integration of three latent variables and ten ordinal indicators. The findings highlighted the significance of integrating subjective attitudinal variables in predicting school mode selection. The findings reveal that the characteristics of the transport network, including the presence of bicycle paths, bicycle parking, and wide sidewalks, greatly influence teens' mode choice behavior for active transportation. Safety awareness positively influences the selection of car mode and enhances bus and pedestrian safety effectively conveying the enhancements to the public, particularly to females. The model application also offers significant insights into the benefits of investing in bicycle and pedestrian infrastructure.

Table 1: The review of explanatory and latent variables in previous research

	Author	Country	Techniques of analysis	Explanatory variables	latent variables
1	Kamargianni and Polydoropoulou (2013) [26]	Cyprus	MIMIC model	- Socioeconomic, - travel time, - travel cost, - parking place, - bike path, - wide sidewalks	
2	Paulssen et al. (2014). [25]	German	- ICLV - MIMIC model, - A cross-nested normal error component logit-mixture (NECLM) model	- Socioeconomic, - car-ownership	- Flexibility, - Ownership, - Comfort and Convenience, - Security, - feeling pleasure, -Power
3	Maldonado-Hinarejos et al. (2014) [28]	London	- MNL models, - Mixed Logit	- Socioeconomic, - environmental and geographical variables, - cycling infrastructure - travel time, - travel cost - land use.	(19 question) - Pro-bike - Image - Context - Stress.
4	Kamargianni et al. (2015) [24]	Cyprus	- Multinomial probit (MNP) model	- Socioeconomic, - Sports as a hobby, - Participate in sports activity	- safety-consciousness, - green-lifestyle - physical activity propensity.
5	Fernández-Heredia et al. (2016) [33]	Madrid, Spain	- ICLV, - MIMIC model	users' characteristics - Socioeconomic, - car availability, - bicycle use trip characteristics, - time, - cost and - distance - Safety, - availability of public transport, - safe bike storage, - flexibility	- economic, - fun, - healthy, - ecological, - flexibility, - efficiency, - comfort, - long distances, - fitness topography, - weather, - vandalism and auxiliary facilities
6	Alex et al. (2016) [34]	developing country	- MNL	- Socioeconomic,	- Comfort and convenience - Habit of the commuter, - travel cost, - travel time, - Safety - Cleanliness - Life style - Reliability
7	Muñoz et al. (2016) [5]	Gasteiz (Spain)	- EFA - Binary logistic	- Socioeconomic, - Car licence,	- Lifestyle, - Safety and comfort,

			regression model	- Car availability, - Know how to ride, - Bicycle availability, - Bicycle parking at home, - Travel time, - Travel distance.	- Awareness, - Direct disadvantages
8	Ding et al (2017) [17]	China	ICLV	<u>Individual characteristics</u> - Socioeconomic, - Bus card Driver license <u>Household characteristic</u>s - Household children - Car ownership - Bicycle ownership	- environmental pollution - physical exercise and keeping fit - satisfying daily travel
9	Sarkar and Mallikarjuna, (2018) [7]	India	- MNL	- Socioeconomic, - vehicle ownership, - driving license,	- comfort, - safety, - flexibility, - reliability
10	Hess et al. (2018) [35]	United States	- ICLV - Bayesian Deficient design - Mixed Logit model	- Socioeconomic, - geography	- sociability, - cars, - privacy, - (information) technology
11	Fitch et al. (2019) [37]	Northern California	- MNL - Bayesian analysis framework	- Distance - Age - Parent High Education - Non-White or Asian - On-campus Parking - Number of Signals	- Enjoyment - Self-image - Social pressure - Environment
12	Singleton (2019) [36]	Portland, Oregon	- (EFA/CFA) - a Satorra-Bentler scaled test statistic, - (MIMIC) models	- Socioeconomic, - Race/ethnicity,	- Satisfaction with Travel Scale - distress, - fear, - attentiveness, - Enjoyment - security, - autonomy, - confidence, - health
13	Sottile et al. (2019) [11]	Cagliari (Italy).	- EFA and PCA - KMO - binary logit model	- Socioeconomic,	- perception of the bicycle - perception of context characteristics - perception of bikeability (utility and safety)
14	García et al. (2019) [38]		- Factorial Analysis technique - KMO	- Socioeconomic,	- affective - cognitive - behavioral
15	Lyu and Forsyth	2021	- Descriptive statistics,	- Socioeconomic, - Car Ownership	- convenience, - pedestrian and

	(2021) [13]		- t-tests, - Analysis of variance (ANOVA), - Hierarchical logistic models, and - Hierarchical linear models	- Employment Status - Self-reported built-environment features - Distance to Work - Distance to City Center - Distance to the nearest Grocery - Distance to the nearest Park - Number of Bus Routes at the nearest stop	cycling safety crossing streets - presence of sidewalks
16	Lizana et al. (2021) [39]	Chilean, Spain	- ICLV, - (MIMIC) - simulated maximum likelihood	- Socioeconomic, - Driver's license	- comfort, - fun, - environmental concern, - economy - health benefits - safety and habit
17	Chan et al. (2021) [19]	Shenzhen	- Binary logistic regression - MLN	- Socioeconomic, - Driver's license, - Length of residency, - Body Mass Index (BMI).	- attitude
18	Mohiuddin et al. (2022) [40]	Bangladesh	- Binary logistic regression	- Socioeconomic, - trip purpose, - mode, - travel time and distance, - the number of bicycles owned, and - car ownership	- walkability (4 indicators) - road safety from traffic (4 indicators) - safety from crimes (2 indicators)
19	Ingvardson et al. (2022)	Copenhagen	- MIMIC model - MNL	- Socioeconomic, - Commute origin - Commute destination - Commuting distance	- existence, - relatedness - growth - Travel difficulties
20	Irawan et al. (2023) [41]	Yogyakarta, Indonesia	- MIMIC - Mixed logit model	- Socioeconomic, - Number of owned cars - Number of owned bikes	- 5 questions on attitudes
21	Shah et al. (2023). [42]	Gujarat state in India	- KMO	- travel cost, - travel time,	- Comfort and Convenience
22	Shah et al. (2023) [43]		- ICLV framework - SEM - MNL	- Socioeconomic, - vehicle ownership, - Distance to the mode	- Safety and Security - Services and Facilities - Riding Attraction and Quality

Fernández-Heredia et al. [33] reinforced the wide range of factors that should go beyond times and costs to properly represent the choice of cycling. They focused also on attitudes and perceptions. They used a hybrid model to investigate the intention of students at universities in Madrid's effect on bicycle use. The hybrid model combines the SEM and the traditional mode choice model. The sample of respondents is limited to students who were studying a new internal bike system. They found that age is more significant when cycling is common to use. The income effect was not clear as it is highly correlated with age. Gender was a key factor where the effect of culture is significant, as male was mostly the only user of cycling. Car ownership had the negative effect of using cycling, but bicycle ownership had a positive effect. These factors were investigated as explanatory factors. Regarding the factors belonging to trip characteristics, time, cost, and distance were the most investigated and significant factors. Safety, availability of public transport, safe bike storage, and flexibility were also investigated. Entertaining, ecological, flexibility, efficiency, comfort, and fitness were considered as the latent variables in this study. The findings highlighted the effects of convenience, pro-bike, physical determinants, and external restrictions. The first two variables were associated with the positive perception of cycling. As the cyclist feels the used mode is efficient, it can be described as convenient. Pro-bike represented the cost of the trip, being healthy and fun. The remaining factors have a negative effect on the perception of cycling, which reflects the physical ability of users, the obstruction of the road design, lack of bike storage, and weather conditions, respectively. They concluded that the incorporation of the latent variables into the mode choice models is an effective way to consider cycling in modal choice.

Alex et al. [34] examined to what extent integrating latent factors into mode choice models affects commuting decisions. The modes analyzed in the study included walking/cycling, automobiles, motorcycles, buses, and trains. A self-descriptive questionnaire was developed, comprising inquiries regarding the respondents' attitudes, behaviors, and socio-demographic factors. The respondents' answers were examined by the EFA employing the main component method to filter indicator variables that significantly affect the attitudes and behaviors of commuters. Five hidden factors remained: comfort and convenience, habit, safety, lifestyle, and reliability. The CFA was performed using SPSS AMOS 20 software to validate the results of the EFA and to establish relationships between indicator variables and latent variables. The SEM was created to associate latent factors with socio-demographic data. Ultimately, two-mode choice models were constructed using Multi Nominal Logit (MNL) models; the first model included sociodemographic data, whereas the second model included latent variables that encompass the socio-demographic variables. Ultimately, model validation revealed that the predictive accuracy of the mode choice model improved by 7.48% when latent data were used in place of socio-demographic variables. This study showed that, in the presence of multimodal conditions, latent variable-enhanced mode choice models are more precise than sociodemographic variable-based models in predicting commuter mode choice.

Muñoz et al. [5] studied the factors affecting bicycle commuting in Vitoria-Gasteiz, Spain based on TPB. To determine the correlations between objective parameters and bicycle or other modes of commuting, categorical methods like Pearson's chi-square test were used. The bicycle's commuting modal share was also analyzed, comparing each category's value in each objective factor. The EFA was used to select the set of latent variables among attitudes, subjective norm, descriptive norm, and PBC (via control capacity and self-efficacy). Lifestyle, safety and comfort, awareness, and direct disadvantages have remained. Socioeconomic and household characteristics, mode availability, and trip characteristics were slightly associated with bicycle commuting. All cycling latent variables were strongly linked with commuting

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mode, but their effect was less than the effect of objective variables.

Ding et al. [17] investigated the impact of incorporating latent variables into the cycling mode choice models and the factors that have a significant impact on the users' attitudes using the data collected from a stated survey in Chinese cities. The investigated factors were grouped into individual and household characteristics, including mode ownership. The integrated DCM and the SEM were used to model the cycling mode choice using the maximum likelihood method based on the M-plus software. The results showed that the latent variables have an important role in the multinomial logit choice model. The most significant factor was pro-bike attitudes. Cronbach's alpha value exceeded 0.60, reflecting the reliability model. The developed hybrid model was compared with the traditional discrete mode choice model. It was concluded that the integrated model had greater explanatory power, reflecting better overall fitness of the model.

Sarkar and Mallikarjuna [7] estimated an ICLV model to understand how latent variables affect mode choice behavior using the most common variables like socioeconomic parameters, comfort, and flexibility. Data from 561 work trips from Agartala, North East. A statistically significant variable was mixed land use, which is the percentage of work area in a 1 km radius of the entire research region. Flexibility and comfort were also found to strongly affect mode choice behavior in the hybrid choice model. The parameters of this model were statistically more significant than the base MNL model estimation parameters.

Hess et al. [35] used stated data from the Northeast Corridor and Cascade Corridor in the US to study intercity travel mode choice drivers. They developed a hybrid choice model to account for deterministic and random preferences among travelers, some of which are tied to attitudinal variables. It showed substantial variation and shed light on behavior determinants and attitudes-choice relationships. West Coast respondents were more anti-car due to public transit quality. The hybrid choice model attributed some variability to four attitudinal constructs: "low sociability," "pro-car," "concern for privacy," and "pro-tech." Mode choice was affected by "pro-car" and "concern for privacy" attitudes. Travelers who liked cars and planes were more inclined to prefer them over buses and trains, as were those who cared more about privacy. Privacy-conscious people are less inclined to take the train than the bus, all else being equal. The remaining two latent attitudes had a smaller effect, although "pro-tech" travelers are less inclined to drive. Key differences were found between attitude and choice drivers. Women are less likely to drive while being more pro-car. However, West Coast respondents were less pro-car but more inclined to choose a car in actual decision scenarios. This proved that attitudes/desires and decisions might differ. Even after controlling for travel time, cost, and service frequency, West Coast respondents had a lower utility for the three non-car options than East Coast respondents, net of attitudinal constructs. The quality of West Coast non-car options may explain this.

Singleton [36] used findings from a survey of 700 commuters in Portland, Oregon, to examine modal variations and other possible factors influencing comprehensive and multidimensional travel metrics. The exogenous factors were trip characteristics, weather conditions, users' demographics, and socioeconomics characteristics, as well as traveler perceptions. Following the development of CFA measurement models for each concept, the SEM that predicts latent variable constructs based on the selected variables provided significant behavioral. Walking and cycling scored far higher on metrics of physical and mental health, self-assurance, and positive emotions, indicating substantial advantages of active commuting. Nevertheless, cycling commuters exhibited elevated levels of negative feelings of security, underscoring the need for multimodal assessments of travel. Improving the quality of the commuting experience through numerous methods—such as creating protected infrastructure to enhance the safety of bicycling—could substantially elevate commuters' well-being.

Sottile et al. [11] examined the influence of bicycle perception as a mode of transport, bike-ability (regarding utility and safety), and cycling infrastructure on the tendency for bicycles to be utilized for utilitarian purposes in Cagliari, Italy. The latent dimensions were determined using Principal Component Analysis (PCA) and Factor Analysis (FA), evaluated by the Kaiser-Meyer-Olkin (KMO) measure and the Scree or Cattell test. Hybrid Choice Models were employed to assess the impact of individuals' perceptions while accounting for the serial correlation among error factors in both discrete and latent perceptions. The model's validity was assessed using a hold-out sample. The findings indicated that, in addition to personal attributes, underlying factors associated with the perception of the environment and the bicycle as a mode of transportation significantly influence the inclination to pedal. The results indicated that young adult males without children in the household had a greater propensity to cycle. The absence of adequate infrastructure and facilities was a significant impediment to bicycle utilization.

Fitch et al. [37] explored the link between choosing cycling to school with attitudes and road environments at three high schools in Northern California. The estimation of the mode choice mode was carried out using MNL. Based on the findings, it appeared that the association between attitudes and cycling was more robust than the relationship between road environments and cycling. One of the most significant associations between bicycling and students was the students' perception of the societal pressure to ride bicycles. The main conclusion was that students would walk and cycle to school at significantly higher rates when suitable infrastructure is available alongside short distances and positive attitudes toward cycling.

García et al [38] evaluated how attitudes and intentions to use active transportation affect travel behavior. The considered indicators of behavior were cognitive, affective, and behavioral views on walking and cycling. The study’s alternative modes were autos, public transport, cycling, and walking. Survey reliability, validity, exploratory and confirmatory factor analysis, and SEM were evaluated. Cronbach's Alpha assessed internal consistency by measuring item relatedness and closeness. Acceptable cycling attitudes tests are cognitive (0.824), affective (0.771), and behavioral (0.704). Cronbach's Alpha was also assessed for walking attitudes' three latent components (cognitive attitudes = 0.705, emotional attitudes = 0.749, behavioral attitudes = 0.610). The last index was barely below the target. As deleting items did not increase the score, extra verifications were needed to determine if the dataset was eligible for factor analysis. Bartlett's sphericity test was null because of this. In addition, the KMO estimated the fraction of variable variance caused by underlying factors. Since values are >0.8, factor analysis may be appropriate. The three latent variables and transit mode items were correlated using Pearson's correlation matrix. On the three theoretical constructs defining attitudes toward each nonmotorized transport mode, two EFAs were done; the first was used to evaluate all pairwise variable relationships and the second was used to retrieve latent factors. The CFA determines if the hypothesized structure fits the data or if observable variables and latent components are connected. CFA models were calculated using robust maximum likelihood. Finally, cognitive, affective, and behavioral attitudes regarding walking, cycling, car, public transit, and walking were examined using two SEM models. The findings showed that intentions to use all the alternative modes affect attitudes toward cycling, walking, and travel mode use. All attitudes affected vehicle, public transport, bicycling, and walking intents and use, with two exceptions. Walking intention decreases with cycling attitude.

Lizana and colleagues [39] conducted an investigation to determine the impact of adding pro-bicycle attitudes and habits, socioeconomic factors, cycling facilities, and bicycling experience as variables on the formation of attitudes. An online survey was developed and distributed to the students and staff members of two Spanish institutions in order to collect ad hoc data. A technique that was based on an integrated choice and latent variable model was utilized in the modeling process. The main key finding is attitude is an applicable construct to explain behavior. It was also concluded that socioeconomic characteristics and bicycling familiarity have a direct effect on bicycle choice. However, the effect of cycling infrastructure was indirect through attitude. Furthermore, the findings indicated that the reduction in the contribution of pro-bicycle attitudes to the explanation of bicycle choice was a consequence of the explicit inclusion of habit. It's possible that this was because of the connection and reinforcement that occurs between attitude and habit.

Mohiuddin et al. [40] investigated the influence of latent perceptions of the built environment, alongside socio-demographic factors, on the walking and cycling preferences of students and non-students in Rajshahi, Bangladesh. The data was gathered via a survey and analyzed using the ICLV framework to integrate the latent variables. Two models were created. The initial model was used for commuting and recreational cycling. The second model pertained to everyday walking trips. The findings indicated that perceptions of safety from crime are the key factor in students' choices for commuting trips, while views and road safety were the factors in choosing cycling for leisure trips. The built environment is the key factor of nonstudents when selecting a bicycle, while their gender was the major predictor of bicycle choice for recreational trips. Additionally, gender indirectly affects bicycling via the hidden perception variable. The findings indicated that travel distance is favorably correlated with leisure bicycling for both students and nonstudents; however, travel distance did not influence work-related riding for students. In addition, it was indicated that hidden perception variables substantially affected individuals' decisions to cycle for commuting and leisure activities.

Ingvardson et al. [41] used the ICLV to process data collected through a survey of commuters in Greater Copenhagen, where there were dense vehicles, public transportation, and bicycle users. Two MNLs mode choice models were estimated comparably. The first model followed the ICLV model except for the latent variables. In contrast, the second model estimated the optimum model using the available information and did not consider the ICLV model specification. The model found that a positive riding self-image increased bicycle frequency. Automotive self-concepts positively affected commuting driving, while functional automobile challenges negatively affected it. Latent variables influenced projected mode switches more than level-of-service attributes. This showed that mode choice is highly influenced by mode-specific perceptions and travel concerns. The investigation of mode shifts across latent variables revealed the advantages of ICLV models over basic MNLs and provided deeper insights into travel behavior decisions. The study also indicated that socio-economic factors explained mode choice directly and indirectly by affecting latent variables. This implies that the current ICLV model may evaluate a policy's impact differently from that of the prior ones.

The purpose of the research conducted by Shah et al. [42, 43] was to estimate individual segments of latent variables that were connected with mode choice in the city of Vadodara, which is located in the state of Gujarat in India. The SEM approach was used to acquire the estimations of the latent segmentation. For the purpose of determining attitudes toward the selection of feeder modes, the model was utilized to identify segments of homogenous latent variables. The modes that have been proposed are environmentally friendly. Because of this, 41 latent variables were discovered through the evaluation of the relevant literature. Information was gathered by using a predefined and structured questionnaire. A preliminary CFA was performed with the SPSS software in order to examine the latent variables along with their respective indicators. Six hypotheses were developed in order to ascertain the interaction that exists between the latent variables using the Analysis of Moment Structures (AMOS) program. This was accomplished through the use of SEM. It was determined that the number of indicators should be reduced to 26, taking into account the extraction, outliers, and correlation requirements. The findings showed that the incorporation of latent characteristics, in conjunction with the proposal of an environmentally friendly, would result in an increased mode choice.

Irawan et al. [44] conducted a survey to assess the use of cycling as a replacement mode for motorized vehicles in Yogyakarta, Indonesia. The survey contained seven choice scenarios based on traffic congestion, the presence of bicycle lanes, and parking. The participants were asked to choose between cycling and motorized vehicles in these seven scenarios. Three models were developed: two models were developed using the mixed logit model, and one model was developed using a hybrid modeling framework integrating the MIMIC model with the mixed logit model. The MIMIC model has been used commonly to test the goodness-of-fit measures. The first model considered traffic conditions and bicycle facilities factors, the second model considered socioeconomic attributes such as the effect of cycling as a group with friends, and the third model considered latent variables. In the third model, a measurement equation was integrated with a structural equation. The findings indicated that providing suitable cycling infrastructure had a positive effect on the attitude of road users towards cycling. However, it depended on the distance of the trip; the bike lane was most significant when the trip distance was shorter than 1.6 km. It was also found that there are significant differences in attitudes between males and females. Most of the socioeconomic characteristics affected the cycling choice, except gender and car ownership, which had insignificant effects.

4. Conclusions

This research reviewed literatures that considered latent variables in transportation mode choice. Despite the fact that subjective factors could not be quantified, it has been found that there is an adequate amount of literature that considers them and develops extended discrete choice models to incorporate them. Most of them demonstrated that attitudes have a significant impact on mode choice. The traditional models are not fitted to incorporate attitude into them. Therefore, an extension of the traditional method called integrated choice with latent variables ICLV has been developed, and its fitting was more significant than the traditional methods. In addition, the extended models are capable of incorporating more variables than the traditional models. The set of latent and explanatory indicators could be selected among a group of investigated variables through statistical tests; the most common are EFA and CFA. The ICLV models perform statistically better than the traditional DCM in most of the reviewed studies. Despite that, it has not been applied in most research due to the lack of a common framework. The importance of subjective factors and latent variables in describing and predicting travel behavior should be taken into account by transport planners to study the behavior of all the traditional and new modes of transportation. Therefore, it is recommended that the latent variables be considered in further research on private and public transportation and all the relevant factors.

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