DRAGANA PETROVIĆ, Ph.D.[1]
(Corresponding author)
E-mail: dragana.petrovic@sf.bg.ac.rs
IVAN IVANOVIĆ, Ph.D.[1]
E-mail: i.ivanovic@sf.bg.ac.rs
VLADIMIR ĐORIĆ, Ph.D. [1]
E-mail: v.djoric@sf.bg.ac.rs
JADRANKA JOVIĆ, Ph.D.[1]
E-mail: j.jovic@sf.bg.ac.rs
[1] University of Belgrade
  Faculty of Transport and Traffic Engineering
  Vojvode Stepe 305, 11000 Belgrade, Serbia

IMPACT OF WEATHER CONDITIONS ON TRAVEL DEMAND – THE MOST COMMON RESEARCH METHODS AND APPLIED MODELS

ABSTRACT

This paper presents an overview of the applied research methodologies and developed travel demand models that take weather impact into account. The paper deals with trip generation and modal split as elements of travel demand that best describe changes in the travel behaviour in different weather conditions. The authors herein emphasize the importance of research in local conditions in all climate zones, especially in areas where climate and modal split characteristics are different from those in common research areas. This review is designed as a brief guide on how the impact of weather can be explored in order to encourage conducting research even in the countries where there is no systematic traffic and travel data collection. The stated adaptation technique followed by the panel household travel surveys may be particularly appropriate for those countries. It is concluded that small budgets should not be considered an obstacle, because it is possible to draw reliable conclusions based even on small samples. Moreover, modern research methods enable a cheaper survey process together with the possibility of obtaining higher quality of results. The increasing popularity of research in this field should contribute to the creation of more resilient transport systems all over the world. A special contribution of this paper is the review of research studies carried out in central, western and southern Europe and not mentioned in any review paper before.

KEY WORDS

weather impact; travel behaviour; trip generation; modal split;

1. INTRODUCTION

The transport system is becoming unreliable in adverse weather conditions, particularly in densely populated areas. It is general opinion [1-5] that impacts of climate change and weather conditions on the transport system have not received the necessary attention. Traffic data are collected mainly in good weather conditions during the spring and autumn. Most models used in transportation planning and traffic management do not include parameters that indicate the weather impact, so they are customized for ideal weather conditions [5, 6]. For a long period of time the weather conditions have been generally left out of travel demand studies, or simplified [2, 3, 7].

Nowadays, in most research papers, the impact of weather on the transport system is analysed through its effect upon traffic infrastructure, driver behaviour, and traffic safety. Common weather condition components including rain, snow, and ice could have apparent negative impacts on the transport system like changing the travel demand, reducing capacity, compromising safety conditions, travel mobility, and reliability [8]. In addition to having an impact on the transport system, technical and operational characteristics, adverse weather surely affects the individuals' decisions and consequently, the travel demand. It is known that transport systems operating close to full capacity react highly non-linearly to changes in travel demand, especially to additional travel demand [9]. Adverse

weather might lead to delay, trip postponement, or modal shift, which may further contribute to congestion, especially during peak hours. Recent studies have demonstrated a sizeable impact of weather, primarily on trip generation, choice of destination, and modal split [1] and suggested that weather conditions should be included in traffic demand models [2, 9]. The majority of research papers analyse the weather impact on non-motorized transport due to its greatest exposure to weather conditions.

Therefore, studies about weather impact on travel demand, trip generation and modal split have been most frequently conducted in cities with significant share of non-motorized trips. The fact is that significant changes, especially in the modal split, can be expected under adverse weather influence in these cities. For example, according to Guitink et al. 1994 [10] forty to sixty percent of all trips are made by walking and cycling in medium-sized cities in Germany and the Netherlands and nowadays medium-sized cities in these countries have a non-motorized share of about 20% to 60%. It is interesting that non-motorized travel are mostly walking trips in Germany and bicycle trips in the Netherlands. There are almost 600 cities/city-regions in Europe which are considered as medium-sized, with a population between 100,000 and 500,000 inhabitants [11]. Exploring the impact of weather conditions on travel demand can be of particular importance in all cities with these characteristics. In Germany, even in major cities, non-motorized movements are widely represented with a greater share of pedestrian movements compared to cycling [12] which can be seen in detail at the European Platform on Mobility Management [13]. Some studies [14-18] show that adverse weather has the strongest effect on bicycle trips. However, this effect certainly depends on cultural differences of the residents. In the Netherlands, a significant share of bicycles in the modal split during windy, rainy, and cold days [19] results from a long tradition of bicycle use.

Climatic and weather conditions vary significantly across the world and consequently, weather conditions are expected to have different impacts on travel demand in different climate zones. When estimating transport demand over a longer period of time and under expected climate change, a specific methodology must be applied [20]. The results of weather impact on travel demand acquired on one territory cannot be applied to another [6, 21] due to different weather conditions, cultural and socio-economic characteristics of the residents. Böcker et al. [22] point out the geographical context, transport and land use, climate conditions, cultures, habits, and adaptations as the main reasons for differences in the effects of weather on mobility in different countries. Additionally, the perception of service quality, especially in the public transport, exerts a great influence on the travel mode choice [23], and the fact is that the individuals in different areas perceive the quality of the transport system differently. Weather conditions and their effects on traffic demand might also differ very strongly within the same country, regionally and seasonally [6]. Research in the local conditions is very important, as the only method of reliable identification and modelling the weather impact on the travel demand.

There are two perspectives in this literature review. The first comprises the applied research methodologies and the second comprises the developed trip generation and modal split models, analysed weather condition components and the main findings in terms of applied modelling procedures. An overview of the research papers analysing and modelling the impact of weather on trip generation and modal split is presented in the next sections. This review includes papers investigating impacts of weather conditions on all transport modes. There are many papers that investigate the impact of weather conditions on only one mode or on only non-motorized transport modes, but these papers are not the subject of this review. The review shows an increase in the number of research papers dealing with weather impact on the travel demand in the last decade, including three review studies published by authors Koetse and Rietveld [3], Böcker et al. [1] and Liu et al. [24].

The authors of this paper believe that the review of relevant papers given herein will indicate the best examples that may serve as a starting point for such research in the countries where it has not been conducted yet. The most common methodologies used in investigating the weather impact on trip generation and modal split are presented in the first part of this paper. After that, weather variables and applied procedures for modelling trip generation and modal split in different weather conditions are shown. Research studies about the impact of weather conditions upon travel demand conducted in the Central, Western and Southern Europe are singled out and described in the last section, since most of them had

2. MOST COMMONLY USED RESEARCH METHODOLOGIES

In most research studies, data on travel demand in different weather conditions were collected by the revealed preferences method, based on household travel survey. The household travel survey is the most common method used in transportation planning for collecting travel demand data [25, 26]. The essence of this technique is to record real changes in travel behaviour. Its main limitation is the inability to test alternatives that are not yet present in the transport system [27, 28].

In addition to the revealed preference method, the stated preference method and the stated adaptation are also used. There are two types of stated preference techniques: the first, where the respondents state their preferences through the measuring scale levels, and the second, where the respondents select one of the offered scenarios or attribute combinations [29]. The stated preference technique enables identification of the user choice for a large number of attribute values. Its main limitation is that the respondents do not necessarily behave as they state in the survey and there is always a possibility of inconsistency between the survey results and the reality. Some studies, however, do not show any statistically significant difference between the user statements and their actual behaviour [25, 26].

The stated adaptation technique is very similar and it has been increasingly used. It is based on the statements regarding behaviour changes [28, 30]. The stated preferences technique implies that the respondents present an answer with their preferences regarding the offered scenarios, while in the stated adaptation technique the respondents present an answer whether and how their behaviour would change in the offered scenarios [31], in this case in different weather conditions. The stated adaptation technique provides a clearer insight into individual attitudes and behaviour when facing hypothetical situations, especially concerning traffic conditions [30, 32].

The revealed preference method is used in case of comprehensive and long-term household travel surveys. In other cases, the stated preferences and the stated adaptation are completely valid methods of data collection. Continuous household travel surveys are common for the countries and cities with greater awareness of the importance of these surveys and available funding. The travel surveys carried out once every five or ten years, or even less frequently, are common for the developing countries, where sufficient funds are not available. *Table 1* shows the research methods and sample sizes in relevant studies, emphasizing the sample size variation.

Table 1 – Applied research methodology and sample size in relevant studies

Research method	Sample size (number of respondents)
Revealed preferences	
Aaheim and Hauge [7]	16,383
Anta et al. [36]	99
Böcker et al. [33]	945
Böcker et al. [22]	14,935
Clifton et al. [2]	2,950
Creemers et al. [37]	18,102
Liu et al. [18]	181,814
Liu et al. [38]	13,579
Liu et al. [39]	24,987
Petrović 2017 [34]	392
Rudloff et al. [9]	193
Sabir [19], Sabir et al. [40]	1,035,378
Sabir et al. [41]	530,000
Saneinejad et al. [42], Saneinejad [43]	43.557
Termida et al. [35]	67
Vu and Nguyen [44]	400
Stated preferences	
Anta et al. [36]	99
Berkum et al. [15]	114
Bergström and Magnusson [14]	1,005
Khattak and De Palma [45]	1,218
Palma and Rochat [46]	880
Stated adaptation	
Cools and Creemers [47], Cools et al. [31]	586
Nikolić [48]	301
Petrović 2017 [34]	678
Petrović et al. 2015 [49]	285
Van Stralen et al. [50]	342
Vu and Nguyen [44]	100

Note: Sample size in Aaheim and Hauge [7] is the number of trips, in Creemers et al. [37] it is the number of households

Several studies [33-35] collected revealed preferences based on the panel research. In Böcker et al. [33], there were 945 respondents who recorded travel data for two days during the summer, two days during the autumn and two days during the winter. Petrović 2017 [34] conducted a panel survey with 392 respondents during the days characterised by one of the following four types of weather conditions: warm*2* – mostly dry weather, moderately warm weather with heavy precipitation, moderately cold*2* – mostly dry weather, and cold weather with heavy precipitation. Days for conducting the survey were not determined by seasons, but by the combination of the analysed meteorological conditions. Termida et al. [35] used a panel survey in the form of a longitudinal panel two-week travel diary of 67 individuals in four consecutive waves in four different seasons.

The panel household travel surveys imply observations made repeatedly on the same sample. These surveys enable the collection of travel data during specific time intervals, in this case, characterized by different weather conditions. This research approach can be particularly appropriate for countries where long-term series of national transport survey datasets do not exist. If a model is created based on the panel travel surveys, the trips are nested by research days and respondents, since an individual's adjustments to different weather conditions are probably correlated. This requires independence of recorded data to be explored [33, 37].

It is evident that the reviewed studies vary by the sample size. Sample size depends on the spatial and temporal coverage of the study, research purpose, research method, and target population size. A large sample size may contribute to a higher quality of the research, but it is more important how the sample reflects the structure of the population. In traffic studies, particularly in the household travel surveys, a stratified random sample is most commonly used [51-53]. Selecting this sampling method can be considered completely legitimate when exploring weather impacts on the travel demand. Even studies based on small representative samples may have high-quality conclusions, especially in the case of the panel survey, which is particularly significant for countries where there is no continuous travel data monitoring.

Unlike studies in which travel data in different weather conditions were collected through household travel survey, out of all the reviewed studies only two rely on the data from the automated traffic detectors. Haberl et al. [6] used data recorded on fifty permanent traffic counting stations (traffic volumes and vehicle speed) and weather measurements of eleven permanent monitoring stations for a one-year period as a basis for the research in the federal state of Salzburg. Pillat [54] used local traffic volume and velocity data from 100 detectors as well as weather data, for a time period of four years. Data about travel time and county where the vehicle was registered were recorded on four locations using an automatic number plate recognition system for one year.

Even though the abovementioned modern technologies and equipment for traffic flow data recording are available, the household travel surveys are most commonly used to explore the weather impact on the travel demand. Furthermore, it is a fact that only the household travel surveys provide information on the travel purpose and individual decisions and choices and that modern equipment cannot provide this item of the travel demand data. The household travel surveys ensure collecting the total travel demand and its characteristics (origin, destination, purpose, mode, time) on the sample. By collecting data from the automated traffic detectors, only the total travel demand is quantified. The travel demand characteristics have to be further obtained based on the known socio-economic characteristics of the residents as well as data from the previous household travel surveys.

3. APPLIED MODELLING PROCEDURES

Temperature, precipitation, and wind are the most common factors included when researching the weather impact on the travel demand. Most studies take precipitation (presence and intensity of rain, snow, and hail) as the most important factor. Temperature and wind are considered less important in terms of individual's behaviour [36]; however, these have a significant impact on thermal comfort. Insolation, cloud cover, air pressure, and humidity are rarely examined [1].

Clifton et al. [2] show that sensitivity of car trips to weather conditions may be presented on a higher aggregation level (level of precipitation intensity only, not taking into account the seasonal effects) in comparison to the sensitivity of bicycle trips (level of precipitation intensity separately for each season). Cyclists are directly exposed to weather, and

therefore models should be sensitive to seasonal weather differences. The seasons are often used to represent the usual weather conditions, particularly in modal split models, as in studies [21, 55]. Still, the seasons may mask the daily weather variations because non-typical weather conditions for certain seasons may have a stronger influence on the decisions than usual weather conditions [2]. When creating a travel demand model that contains weather variables, the impact of weather forecast on the individuals' decisions can also be taken into account [47]. It has been demonstrated that weather forecasts affect the travel behaviour [15, 44], but this effect may certainly be considered lower than the impact of the current changes in weather conditions. *Tables 2* and *3* show the components of weather conditions that are analysed and included as weather variables in trip generation and modal split models.

Evidently, the most frequently analysed components of weather conditions are the temperature, the rainfall intensity, and the wind, and these three components are analysed together in almost all the above presented research studies.

Different intensities of weather condition components have a different impact on the travel demand. The more intense weather components (heavy rain, heavy snowfall, extremely low or high temperatures, stronger wind) certainly have a greater impact on the number of trips and modal split. Vu and Nguyen [58] have shown, as logically expected, that urban flood has a stronger effect on travel behavioural changes than heavy rain. Rudloff et al. [9] concluded that the number of trips decreased with the increasing rain, where the impact on leisure trips was the largest. Different impact on transport modes was recorded: walking decreased with increasing precipitation, biking decreased but more sensitively and car driving was almost unaffected. Aaheim and Hauge [7] found that the likelihood of public transport usage increased with the intensity of precipitation and wind, compared to walking and biking. More intense rain, higher temperature or stronger wind lead to a greater probability that people prefer public transport to pedestrian and bicycle if the share of private transport is unaltered, or to private transport if the share of pedestrian and bicycle is unaltered [7]. The conclusion is that the

Table 2 – Weather variables in trip generation modelling

	Anta et al. [36]	Böcker et al. [22]	Böcker et al. [21], Böcker [55]	Clifton et al. [2]	Haberl et al. [6]	Liu et al. [38]	Liu et al. [39]	Liu et al. [56]	Pillat [54]	Rudloff et al. [9]	Sabir et al. [40], Sabir [19]	Termida et al. [35]
Average weather										+		
Bad weather										+		
Good weather										+		
Rain duration											+	
Rain precipitation intensity	+	+		+	+	+	+	+			+	
Relative air humidity				+		+	+					
Season			+	+	+				+			
Snowfall		+			+					+	+	
Snow/ice on road					+	+	+	+				
Sunshine duration					+							
Temperature	+	+		+	+	+	+				+	
UTCI									+			+
Visibility						+	+	+			+	
Wind	+	+		+		+	+				+	

Note: UTCI is Universal Thermal Climate Index (degrees Celsius) on the given day in the given season. UTCI was introduced in 1994. It takes dry temperature, relative humidity, solar radiation, and wind speed into account and is regarded as the reference environmental temperature causing strain. [83]

Table 3 – Weather variables in modal split modelling

	Aaheim and Hauge [7]	Anta et al. [36]	Böcker et al. [21], Böcker [55]	Böcker et al. [22]	Clifton et al.[[2]	Cools and Creemers [47]	Creemers et al. [37]	Khattak and De Palma [45]	Liu et al. [56]	Rudloff et al. [9]	Sabir et al. [57]	Sabir [19]	Saneinejad [43], Saneinejad et al. [42]	Vu and Nguyen [44]
Adverse weather								+						
Cloud cover													+	
First precipitation in 7 days						+								
Fog							+							
Rain duration						+						+		
Rain precipitation intensity	+	+		+	+		+		+	+	+	+	+	+
Relative air humidity					+									
Season		+			+									
Snowfall				+			+					+		
Snow/ice on road									+					
Storm							+							
Sunshine duration						+								
Temperature	+	+		+	+	+	+		+	+	+	+	+	
Thunderstorm						+								
Wind	+	+		+	+					+	+	+	+	

bicycle traffic is under the greatest influence. Heinen et al. [59] concluded that the increase in quantity and duration of rain as well as increase in the wind strength affected cycling negatively, especially for the recreational purposes [14, 16, 17]. The increase in sunshine duration and temperature increase the probability that the commuters will cycle. On the other hand, studies [44, 58] have shown that mode change is very modest in all adverse weather conditions while trip cancelation, delayed departure, waiting for resuming of the trip, route change, and destination change are significant.There are several approaches to include weather conditions in the travel demand models. One approach is to directly include different weather components as continuous variables, and another is to form binary indicators (dummy variables). The third approach is the data reduction technique, which examines the covariance of different weather conditions [2].

Böcker et al. [1] criticize the modelling techniques which assume a linear relationship between weather conditions and trips. In trip generation and modal split modelling, dummy variables for certain components of weather conditions are being increasingly used. This is in accordance with the recommendations to include non-linear variables in the models [27]. Special attention should be given to the fact that certain variables, like type of household, occupation, age, gender, and car number per household, usually show a non-linear dependence. The proposed methods to include these variables into the models are either a variable transformation (linearisation) or the use of dummy variables. The use of dummy variables, in addition to solving the problem of non-linearity, usually contributes to solving the problem of multicollinearity i.e. high degree of correlation of independent variables [27].

Research studies should include impacts of weather on all aspects of travel behaviour: number of trips, spatial and temporal distribution (destination choice, departure time and trip duration) and modal split. This is the only way to determine what changes are the result of different weather conditions, as changes in travel behaviour may be interdependent.

3.1 Trip generation modelling

Regression and cross-classification models are widely used in trip generation modelling. Although their results show an acceptable level of accuracy for transportation planning, these models have shortcomings as well (e.g. not taking into account the user behaviour, dependent variable can have negative or a non-integer value, which is not the case in reality). Models recommended as an alternative to conventional trip generation models are: tobit model, Poisson model, ordered logit model, ordered probit model, negative binomial model, truncated models as an alternative to regression models and multiple classification analyses as an alternative to cross-classification models [60].

A series of models were used to model the weather impact on trip generation (*Table 4*). These models follow the recommendations [60] for replacement of conventional models which do not take into account the user behaviour. Negative binomial and tobit models are most often used for trip generation modelling in different weather conditions. When travel demand is evaluated as the number of trips, the negative binomial model is used as a reference model for the count data. Travel demand evaluation may also be based on the distance travelled by individuals during the day and then the travel demand is estimated by the tobit model. The tobit model is implemented mainly due to the non-negative value of the dependent variable and because there is a possibility that many respondents, for example, do not have any trips of specific purpose registered during the day [55].

3.2 Modal split modelling

Many factors influence the travel mode choice. Models must be sensitive to numerous characteristics of the passenger, journey, and transport facilities. The multinomial logit model is commonly used in relevant studies dealing with modal split modelling that includes weather impact (*Table 5*) due to its simplicity. An important function of the multinomial logit model is to determine the impact of certain independent variables on the individual choice within a discrete set of options. In this case, weather is one of the independent variables and travel mode choice in different weather conditions is the dependent variable. Wider application of some other models can be expected in the future, especially in cases where panel studies should be applied.

4. RESEARCH STUDIES IN EUROPE NOT ANALYSED BEFORE

Weather impact on individual behaviour and travel demand was explored in regions of the USA, Australia, Europe, and Asia. The largest number of research activities was conducted in the countries of Northern Europe, mostly in the Netherlands. This indicates that the studies were conducted predominantly in the cold climate areas. A high share of non-motorized transport modes in the modal split may be highlighted as one of the main reasons for continuity in research in the Netherlands, because the users there are mainly exposed to adverse weather. After the Netherlands, this type of research is most common in the cities of Sweden and Belgium, where

Table 4 – Models used for trip generation modelling in different weather conditions

Models	Authors
Factor analysis; cluster analysis; regression models	Clifton et al. [2]
Inverse Gaussian GEE model	Petrović 2017 [34]
Linear regression; cluster model; behavioural travel demand model; combining cluster model and travel demand model	Pillat [54]
Multiple regression analysis	Haberl et al. [6]
Negative binomial	Sabir et al. [40], Sabir [19], Liu et al. [39]
Ordered logit model	Rudloff et al. [9]
Panel mixed ordered probit models	Liu et al. [56]
Simultaneous tobit models	Liu et al. [38], Termida et al. [35]
Structural equation models	Liu et al. [39]
Tobit model	Sabir et al. [40], Sabir [19], Böcker et al. [21], Böcker [55], Liu et al. [39]

Note: GEE - Generalized Estimating Equations

Table 5 – Models used for modal split modelling in different weather conditions

Models	Authors
Binary logit model	Vu and Nguyen [44]
Binomial logit GEE model	Petrović 2017 [34]
Generalised structural equation models	Böcker et al. [22]
Factor analysis; cluster analysis; regression models	Clifton et al. [2]
Mixed logit model	Rudloff et al. [9]
MNL-GEE regression model	Cools and Creemers [47], Creemers et al. [37]
Multinomial logit model	Sabir et al. [41, Sabir [19], Saneinejad [43], Saneinejad et al. [42], Böcker et al. [21], Böcker [55], Liu et al. [18], Anta et al. [36]
Ordered probit model	Khattak and De Palma [45]
Quantal response model	Aaheim and Hauge [7]

Note: MNL - Multinomial logit

there is also a large share of non-motorized trips [13] in the modal split. The share of non-motorized trips in Denmark is very similar [13] to the Netherlands, and Denmark is also recognized as a European country where the bicycle is the national symbol [61]. However, research on the weather conditions impact on the travel demand is not represented in Denmark as in the case of the Netherlands, Sweden and Belgium. There is also a large number of cities in Germany and Spain with significant share of non-motorized trips, but this type of research is rare.

In recent years the studies about weather impact on travel demand have been carried out in the European countries with climatic conditions significantly different from Northern Europe, like Austria, Germany, Serbia, and Spain. Most of these papers, except Anta et al. [36], have not been cited in papers dealing with weather impact on travel demand, thus indicating that insufficient attention is paid to research studies in these parts of Europe. The statement that it is important to explore the weather impact on travel demand in different climate areas is confirmed by several published papers described below.

In the province of Salzburg (Austria), Haberl et al. [6] investigated the influence of weather conditions on leisure traffic demand, as destination and departure time choice depend greatly on the season and weather conditions. The authors set up the hypothesis that weather data could be useful for a more accurate prediction of leisure trips. It was shown that temperature, sunshine hours, and fresh snowfall had the highest impact, while precipitation and snow depth had less impact on the traffic demand during the winter. During the summer, the temperature and sunshine hours had the highest impact on the traffic demand. Although the authors stressed the potential of integrating weather conditions to predict the traffic demand, the weather conditions were not considered in the demand model. The authors gave the following explanations: "still relatively low explanation for the variance of the weather parameters on traffic demand, the valid weather forecast was hard to obtain, weather phenomena and their effects differ regionally and seasonally very strongly".

Rudloff et al. [9] showed that precipitation and temperature influenced travel choices in Vienna (Austria). The highest reduction in activity was found for precipitation, hot weather, and cold weather, mainly in the case of leisure trips. Biking mainly, together with walking, is the most affected mode, while car trips are not strongly influenced by the weather. Public transport attracts more trips during the days with adverse weather and the trips are shifted from walking and biking.

In the South-eastern part of Bavaria in Germany, Pillat [54] developed methods for analysing and forecasting the impacts of weather on the traffic volume on motorways. The regression analysis showed a highly significant influence of weather on the total traffic volume, especially on leisure trips. It was also examined if the integration of weather effects in transport models would improve the forecast quality. It was concluded that the qualitative and quantitative characteristics of the weather effect were related to the day of the week, time of day and spatial location of the analysed motorway section. The quality of forecast was evaluated based on the average GEH index, which makes this particular paper the only one using this approach. The GEH

index is a formula used in traffic engineering, traffic forecasting, and traffic modelling to compare two sets of traffic volumes. The authors concluded that the inclusion of weather effects in the cluster model increased the forecast quality in most cases, but the inclusion of weather impact in transport models did not necessarily guarantee a higher forecasting quality. It was concluded that modelling of additional influencing factors, such as holiday trips, was required in order to produce a fundamental improvement.

Petrović et al. 2015 [49] investigated the weather impact on transport supply and demand. The research showed that adverse weather conditions had a greater impact on leisure trips than on work travel. In adverse weather conditions, the employed residents usually decided to cancel their leisure trips and, to a lower percentage, to postpone them. Work trips were rarely cancelled. These changes were reflected in the mode choice and the starting time represented by the shift of the morning peak period.

The influence of weather on the motorized modes of travel (bus, rail, and passenger car, as possible alternatives) was investigated on one of the most important corridors in Barcelona (Spain). Anta et al. [36] concluded that the travellers preferred to use rail compared to the bus in adverse weather conditions. On the other hand, bus was more likely to be used than a passenger car, because of bus priority on some sections of the corridor.

5. CONCLUSIONS FROM RECENT RESEARCH PAPERS

The focus of the papers published in the last two years [62-67] was on the weather impact on public transport ridership in Australia, China, and the United States. These papers may be considered as indicators of the growing interest in investigating the weather impact on public transport, which further indicates that there is a non-negligible influence of weather conditions on the transport demand and mode choice. The papers from China [68] and Indonesia [69] that analyse the impact of weather conditions on taxi passengers and on online transportation (Go Car / Grab Car) indicate that the research of this kind extends to all transport subsystems.

Variations in weather conditions during the day have an impact on hourly public transport ridership, where the influence varies between peak and off-peak hours, weekdays and weekends, different transit modes and different groups of public transport users

which indicate the need to investigate this subject in more detail. For the prediction of travel demand in order to create a resilient public transport system, several models have been developed. Research on the impact of weather on public transport confirms the importance of conducting research regardless of the share of non-motorized trips in the modal split, since public transport users are also significantly exposed to weather conditions during access and egress.

The most recently published paper [22] confirms the importance of research at the local level, indicating different impacts of weather conditions in different regions. It is important to perform research locally, so all specific characteristics of the area and its inhabitants could be incorporated into the demand model. Adjustments to specific characteristics of the area and its population should provide a valid prediction of weather impact on trip generation and modal split.

Travel survey methods strive toward modern technologies. Technology-mediated travel survey methods enable capturing of more details in individual travel behaviour [70] and help reporting on non-motorised trips more accurately [70, 71], help in reducing under-reporting of trips, and over-estimating of travel times, inaccuracy of locations and times [72] with the possibility of obtaining a higher quality of results [73]. Examples can be found only in [34, 49, 74] in the form of an internet-based travel behaviour survey. The research focused on public transport ridership, mainly use of the Automatic Fare Collection (AFC) system for ridership data collection, which shows a great potential of smart technologies as a source of information that could complement or even sometimes substitute regular surveys [75].

6. DISSCUSION AND CONCLUSION

Modelling the travel demand for different weather conditions is important because travel demand varies significantly in different weather conditions. Models that do not take weather conditions into account cannot be considered accurate enough for the presentation of travel demand in a particular area during periods with weather conditions different than the average. The researchers who would undertake a study on this subject in the future could find the appropriate type of model for predicting the weather impact on the travel demand, according to the data collected and respecting the basic principles of

modeling the weather impact on transport demand that are outlined in this paper. The influence of a large number of weather components on the travel demand can be examined, bearing in mind that the temperature, precipitation, and wind are represented most in the developed models.

Data obtained locally from this kind of research are of great importance for understanding the impact of weather conditions on the travel demand. Standard travel demand and supply studies are conducted in ideal weather conditions and thus the obtained values cannot be used to evaluate the operation of the transport system, nor to make traffic management decisions in adverse weather. This type of research and the conclusions drawn at the local level are necessary for realistic representations of travel behaviour in different weather conditions for the purpose of travel demand modelling. Mathematical models that have been developed in the presented studies can be further used for the modification of the standard functions in travel demand modelling software.

For comprehensive traffic modelling, it is necessary to introduce the coefficients that describe the sensitivity of both demand and supply in different weather conditions. A fact stated by Stahel [76], that there is lack of comprehensive simulation tool that can thoroughly model weather sensitivity of the transport system, is still valid. Weather-sensitive models treat impacts on transport infrastructure and driving behaviour, or include very simple activity-travel behaviour models [76]. It is not a simple process to capture all the potential effects of adverse weather conditions on transport supply and demand, to research, quantify and include them in the simulation tools. Comprehensive research on travel supply and demand in different weather conditions is particularly expensive and organizationally challenging. The application of traffic simulation software is most often related to the assessment of the weather conditions impact on the traffic system for evacuation analysis. Microscopic simulation models are a more popular tool for the evacuation analysis than mesoscopic and macroscopic models. Macroscopic models cannot present the individual vehicles behaviour in different weather conditions and mesoscopic models can track vehicle platoon dynamics, but not detailed individual vehicles behaviour [77]. Macroscopic models can show a detailed weather impact on travel demand with an activity-based models if less detailed impact on

travel supply is acceptable. Agent-based micro and mesoscopic simulations were used [76-78] for traffic modelling in different weather conditions since it allows modelling of complex systems based on the behaviours of the individual actors involved [76]. Considering that in the future the goal will be to analyse the impact of weather conditions on the detailed temporal and spatial level, it would be important to define the coefficients of sensitivity of all the elements of supply and demand of the transport system so that the results can be presented in the simulation software at the micro, meso and macro levels. Simulation methods will certainly provide possibilities to test and analyse different kinds of "what-if" scenarios of the transport system [79] in different weather conditions.

It would be significant to include the traffic modelling results mentioned above in the transport master plans as they are made for the purpose of assessing the long-range investments in the transport sector. Quantifications of the weather conditions impact would be necessary in all transport sectors having in mind the comprehensiveness of the transport master plans. Future traffic demand management strategies and possible flexibility in road and street network and public transport capacities could be defined in accordance with the expected weather conditions and their impact on the transport system elements. The capacity flexibility in different weather conditions may be achieved by various traffic management models.

This literature review indicates a need to explore the weather impact on transport demand in all areas regardless of their climate. Research in local conditions is the only method of reliable identification and modelling the weather impact on the travel demand. One of the main goals of this review paper is to emphasize the importance of exploring the weather impact on travel behaviour and travel demand in areas where non-motorized modes, primarily bicycle, do not have a dominant share in the modal split. The modal shift between walking and motorized transport, as well as between public transport and passenger cars has not been sufficiently explored. The research in this field is important for defining and developing traffic management strategies, as motorized modes of transport have a high share in the modal split with a significant negative impact on the environment [80]. Besides, the fact is that the number of studies

conducted in the developing countries is quite limited [58], so the research should be initiated in these countries as well.

In analysing and modelling the weather impact on overall travel demand, only continuous household travel surveys provide continuous travel behaviour monitoring and therefore matching travel databases with weather databases. In the absence of continuous household travel surveys, the research activities may start with a stated adaptation survey. It would serve as the basis for establishing whether or not there are changes in the travel demand in different weather conditions. If it is determined that the changes do exist, the obtained results may be validated by the revealed preferences using panel surveys. For each data collection technique mentioned herein, stratified sampling is recommended as a valid sampling method in traffic studies, particularly in travel surveys.

This review paper aims to raise awareness about research possibilities even in areas where there is no systematic traffic and travel data collection. In this case, research can rely on modern technology-mediated travel survey methods as they reduce survey costs and respondent burden. It is important to keep in mind that even studies based on small representative samples may have high-quality conclusions. Panel household travel surveys can be particularly appropriate for countries where long term series of national transport survey datasets do not exist.

Authors believe that research in this area will certainly contribute to climate adaptation within the existing strategies and procedures as part of contemporary ideas about climate adaptation as business as usual [81, 82]. Future analysis in this research area will rely on collecting detailed data that will indicate reactions to changes in weather conditions throughout the day that often occur in short time intervals. In the future, the authors will focus on the research on the weather impact on the travel demand and supply in cities in the region, focusing on the weather effect on the modal split. An additional goal will be to show the impact of weather conditions on the transport supply and demand in traffic simulation software at the macro level. Besides, it would be interesting to conduct a research in the European cities with significant public transport share in the modal split, which may further confirm the fact that this kind of research is important in all climates regardless of the modal split.

Dr **DRAGANA PETROVIĆ**[1]
E-mail: dragana.petrovic@sf.bg.ac.rs
Dr **IVAN IVANOVIĆ**[1]
E-mail: i.ivanovic@sf.bg.ac.rs
Dr **VLADIMIR ĐORIĆ**[1]
E-mail: v.djoric@sf.bg.ac.rs
Dr **JADRANKA JOVIĆ**[1]
E-mail: j.jovic@sf.bg.ac.rs
[1] Univerzitet u Beogradu, Saobraćajni fakultet
   Vojvode Stepe 305, 11000 Beograd, Srbija

UTICAJ VREMENSKIH USLOVA NA TRANSPORTNU POTRAŽNJU – NAJČEŠĆE METODE ISTRAŽIVANJA I PRIMENJENI MODELI

REZIME

Rad predstavlja pregled primenjenih metoda istraživanja i razvijenih modela transportne potražnje koji uzimaju u obzir uticaj vremenskih uslova. Ovaj rad se bavi nastajanjem putovanja i vidovnom raspodelom kao elementima transportne potražnje koji najbolje opisuju promene u ponašanju putnika u različitim vremenskim uslovima. Autori naglašavaju važnost istraživanja na lokalnom nivou u svim klimatskim uslovima, posebno u oblastima u kojima se karakteristike klime i vidovne raspodele razlikuju od onih u oblastima u kojima su istraživanja najčešća. Ovaj pregled osmišljen je kao kratki vodič o tome kako se može istražiti uticaj vremenskih uslova, sa ciljem podsticanja istraživanja čak i u zemljama gde ne postoji sistematsko prikupljanje podataka o saobraćaju i karakteristikama kretanja. Tehnika „izjavljenih prilagođavanja" praćena panel anketama o kretanjima sprovedenim na nivou domaćinstva može biti posebno pogodna za takve zemlje. Zaključeno je da mala finansijska sredstva raspoloživa za istraživanja ne bi trebalo smatrati preprekom, jer je do pouzdananih zaključaka moguće doći čak i na malim uzorcima. Štaviše, savremene metode istraživanja omogućavaju jeftinija istraživanja uz mogućnost dobijanja većeg kvaliteta rezultata. Porast popularnosti istraživanja u ovoj oblasti trebalo bi da doprinese stvaranju otpornijih transportnih sistema širom sveta. Poseban doprinos ovog rada je pregled istraživanja sprovedenih u centralnoj, zapadnoj i južnoj Evropi koja nisu pomenuta ni u jednom od prethodnih preglednih radova.

KLJUČNE REČI

uticaj vremenskih uslova; ponašanje putnika; nastajanje kretanja; vidovna raspodela;

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