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CHANGES IN TRAVEL BEHAVIOR IN RESPONSE TO WEATHER CONDITIONS: WHETHER TYPE OF WEATHER AND TRIP PURPOSE MATTER?

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ABSTRACT

Weather events can affect traffic in various ways; it can influence travel demand, traffic flows and traffic safety. This paper focuses on the impact of weather conditions on travel demand. The main objectives of this paper are to test the hypothesis that the type of weather determines the likelihood of a change in travel behavior and to assay whether the changes in travel behavior due to weather conditions are dependent on the trip purpose. To this end, a stated adaptation study was conducted in Flanders (Dutch speaking region of Belgium). In total 586 respondents completed the survey, which was administered both on the Internet and via a traditional paper-and-pencil questionnaire. To ensure an optimal correspondence between the survey sample composition and the Flemish population, the observations in the sample are weighted. To test the main hypotheses Pearson chi-square independence tests will be performed. Both the results from the descriptive analysis and the independence tests confirm that the type of weather matters, and that the changes in travel behavior in response to these weather conditions are highly dependent on the trip purpose. This dependence of behavioral adjustments on trip purposes provides policy makers with a deeper understanding of how weather conditions affect traffic. Further generalizations of the findings are possible by shifting the scope towards revealed travel behavior. Triangulation of both stated and revealed travel behavior on the one hand, and traffic intensities on the other hand, is certainly a key challenge for further research.

1 BACKGROUND

A deeper understanding of how various weather conditions affect traffic is essential for policy makers. This is stressed by policy issues which are often related with adverse weather events such as increased fuel consumption, economic losses due to traffic delays, and higher traffic counts. At network level, adverse weather events increase the uncertainty in system performance, resulting for instance in a network capacity reduction ranging from 10 to 20% in heavy rain (*1*). Maze et al. (*2*) reported that weather events affect three predominant traffic variables: travel demand, traffic safety and the traffic flow relationship. This paper focuses on the impact of weather on travel demand.

Weather can influence travel demand in different ways, including diversions of trips to other modes or other paths, or even cancellations of trips (*2*). Day-to-day weather conditions such as fog and precipitation can decrease travel demand, for instance when drivers postpone or cancel discretionary activities (e.g. leisure activities), but can also have an increasing effect when travel modes are shifted from slow modes (walking, cycling) towards motorized vehicles (*3*). Mode changes, changes in departure time and diversions to alternate route, were reported by Khattak and De Palma (*4*) as the most prevalent behavioral adaptations. Bos (*5*) indicated that in the Netherlands heavy rain reduces the number of cyclists, whereas mild winters and warm summers increase bicycle use. Van Berkum et al. (*6*) noted that the reduction in bicycle use during heavy rain is accompanied by a modal shift from bicycle to car (either driver or passenger). A similar result was found by Nankervis (*7*), who examined the effect of both (short-term) weather conditions and (long-term) seasonal variation patterns on bicycle commuting patterns among students in the temperate climate of Melbourne, Australia: cycle commuting was affected by long-term, climatic conditions as well as daily weather conditions. According to Guo et al. (*8*) temperature, rain, snow and wind all influence transit ridership of the Chicago Transit Authority: good weather increases ridership, while bad weather has a diminishing effect. Guo et al. (*8*) also stressed that next to transit ridership, also vehicle running and dwell times, as well as the cost of operation, are affected by weather. In Brussels (Belgium) on the other hand, the transit agency reported higher levels of transit ridership during adverse weather (*4*).

The main objectives of this paper are to test the hypothesis that the type of weather influences the likelihood of a change in travel behavior (e.g. assessing whether more people change their transport mode during snow than during periods of fog) and to assay whether the changes in travel behavior due to weather conditions are dependent on the trip purpose (e.g. examining whether due to snowy weather more people cancel their leisure and shopping trips than school/work related trips). To this end, a stated adaptation study was conducted in Flanders (Dutch speaking region of Belgium).

The remainder of this paper is organized as follows. Section 2 addresses the methodology that has been used throughout the research, followed by a descriptive analysis of the behavioral adaptations enticed by weather conditions in Section 3. Section 4 provides the results and corresponding discussion of the statistical analysis of the two hypotheses. Finally, some general conclusions will be formulated and avenues for further research indicated.

2 METHODOLOGY

2.1 A Stated Adaptation Approach

The data needed to address the main research questions were collected by means of a stated adaptation experiment. Different definitions about stated adaptation experiments can be found in literature (*9,10*). In this paper, stated adaptation experiments are regarded as an alternative to the more widely used stated preference and choice experiments. The main difference between stated adaptation and stated preference and choice experiments is the task posed to the respondents. In stated preference experiments, respondents are requested to indicate their preference to sequentially presented attribute profiles. In stated choice experiments, respondents are shown choice sets of two or more attribute profiles and are asked to choose the profile they like best (or alternatively allocate some fixed budget among the profile). In stated adaptation experiments, respondents are asked to indicate if and how they would change their behavior considering experimentally varied attribute profiles, typically representing scenarios, in this paper the different weather conditions.

In total 586 respondents completed the stated adaptation survey, which was administered both on the Internet (13.3%) and via a traditional paper-and-pencil questionnaire (86.7%). The choice for this dual mode administration was made to remedy the sample bias that is introduced when only an internet-based data collection is conducted. After all, previous studies have demonstrated that some socio-economic classes of society, like older-age and lower-education groups, may be more reluctant towards using computer-assisted instruments for the data collection (*11,12*). In total 90 behavioral adaptations in response to different weather conditions were queried; the frequencies of 5 travel behavior changes in response to 6 weather conditions were surveyed, and this was repeated for 3 types of trips. An elaboration on these different items will be provided in the following subsections.

2.1.1 Weather Conditions

The following weather conditions were considered: cold temperature (defined as temperatures below freezing (0° C, 32° F), abbreviated as 'cold'), warm temperature (defined as temperatures above 28° C (82.4° F), abbreviated as 'warm'), snow/freezing rain, heavy rain/thunderstorm (abbreviated as 'rain'), fog and storm/heavy wind. Note that Cools et al. (*13*) reported that these weather conditions had a significant impact on daily traffic intensities measured on Belgian highways. Therefore, the decision was made to analyze the impact of these weather conditions on the underlying travel behavior. To provide a better understanding of how frequent these weather events occur, various weather-related measures are provided in Table 1. In addition, it is noteworthy to mention that in general, Flanders has a moderate maritime climate.

TABLE 1 Weather Parameters measured in Uccle [1] (nearby Brussels, Belgium)

Parameter	2007	2008	Normal [2]
Average wind speed (m/s)	3.3	3.4	3.7
Sunshine duration (h)	1472.0	1449.0	1554.0
Average temperature (°C)	11.5	10.9	9.7
Average maximum temperature (°C)	15.3	14.6	13.8
Average minimum temperature (°C)	7.8	7.2	6.7
Absolute maximum temperature (°C)	30.9	31.0	31.7
Absolute minimum temperature (°C)	-6.8	-6.1	-8.9
Number of freezing days (min < 0°C)	27.0	37.0	47.0
Number of wintry days (max < 0°C)	1.0	0.0	8.0
Number of summery days (max >= 25 °C)	23.0	25.0	25.0
Number of heat wave days (max >= 30°C)	2.0	1.0	3.0
Average relative atmospheric humidity (%)	80.0	77.0	81.0
Total precipitation (mm)	879.5	861.5	804.8
Number of days with measurable precipitation (>= 0,1 mm)	204.0	209.0	207.0
Number of days with thunderstorm	94.0	95.0	94.0

[1] Source: Royal Meteorological Institute of Belgium (*14*)
[2] Normal: long-term meteorological average (1971-2000)

2.1.2 Changes in Travel Behavior

The stated adaptation questionnaire was subdivided into three parts, corresponding to the three types of trips that were considered for the analysis. These three types of trips correspond to the categories of most commonly performed trips according to the Flemish travel behavior survey (*15*); namely commuting (work/school), shopping and leisure trips. Equivalent questions were asked in each part: for a certain behavioral change, the respondents had to indicate how often (never, in 1-25% of the cases, in 26-50% of the cases, or in more than 50% of the cases) they make a certain change in travel behavior for each of the six weather conditions. The following changes in travel behavior were queried: (i) a change in transport mode, (ii) a change in timing of the trip (postponement/advancing of the trip to a later/earlier moment on the same day), (iii) a change in the location where the activity (work/school, shopping or leisure) will be performed, (iv) elimination of the trip by skipping the activity (trip cancellation), and (v) a change in the route of the trip. To illustrate the questionnaire style, Figure 1 displays the question concerning the postponement/advancing of work/school-related trips to a later/earlier moment the same day.

Do you postpone or advance your work/school-related trip to a later/earlier moment the same day due to any of the following weather conditions?

Mark the answer that corresponds mostly to your situation. Only ***one*** *answer is possible for* ***each weather condition****.*

	No, never	Yes, occasionally (<25% of the cases)	Yes, sometimes (<50% of the cases)	Yes, usually (>50% of the cases)
Cold temperature	○	○	○	○
Snow/freezing rain	○	○	○	○
Heavy rain/thunderstorm	○	○	○	○
Fog	○	○	○	○
Warm temperature	○	○	○	○
Storm/heavy wind	○	○	○	○

FIGURE 1 Stated adaptation question concerning postponement/advancing work/school-related trip.

2.2 Statistical Analyses

In order to guarantee an optimal correspondence between the survey sample composition and the Flemish population, the observations in the sample are weighted. The weights were calculated by matching the marginal distributions of the sample with the marginal distributions of the population. Age, gender and civil state were the basis for this matching process. Recall that the main objectives of this paper are to test the hypothesis that the type of weather determines the likelihood of a change in travel behavior and to assay whether the changes in travel behavior due to weather conditions are associated with the type of trip. To test these hypotheses, independence tests will be performed.

To test independence (this is the null hypothesis) between two multinomial (categorical) variables one could use the Pearson statistic Q_p, which is defined by the following equation:

$$Q_p = \sum_{i=1}^{k} \sum_{j=1}^{l} \frac{\left(n_{ij} - \hat{\mu}_{ij}\right)^2}{\hat{\mu}_{ij}},$$

where n_{ij} is the observed frequency in cell (i,j) , calculated by the multiplying the observed chance by the sample size, and $\hat{\mu}_{ij}$ is the expected frequency for table cell (i,j). When the row and column variables are independent, Q_p has an asymptotic chi-square distribution with (k -1)(l - 1) degrees of freedom (*16*).

One criticism of the Pearson statistic, is that is does not give a meaningful description of the degree of dependence (or strength of association). The Cramer's contingency coefficient, often referred to as Cramer's V, is one method to interpret the strength of association, and is calculated using the following formula:

$$V = \sqrt{\frac{Q_p}{N\left(m-1\right)}},$$

where Q_p is the Pearson chi-square statistic defined above, N is the total sample size and m is the minimum of the number of rows and the number of columns in the contingency table. Basically, Cramer's V scales the chi-square statistic Q_p to a value between 0 (no association) and 1 (maximum association). Note that Cramer's V has the desirable property of scale invariance: i.e. if the sample size increases, the value of Cramer's V does not change as long as values in the contingency table change the same relative to each other (*17*).

3 DESCRIPTIVE ANALYSIS OF THE CHANGES IN TRAVEL BEHAVIOR

Before elaborating on the formal testing of the main hypothesis in Section 4, in this section a descriptive analysis of the behavioral adaptations enticed by weather conditions is provided. First, the changes in commuting (work/school) related trips are discussed. Afterwards, behavioral alterations of shopping trips are examined. Finally, a closer look is taken at the adaptations in leisure trips. To improve readability, conditional probabilities of people making behavioral adaptations are displayed rather than absolute numbers.

3.1 Changes in Commuting Trips

For the commuting (work/school) trips, the percentages of respondents making a certain travel behavior change are displayed in Table 2. When the different weather conditions are compared, it is immediately clear that snow has the largest impact on commuting trips. Especially time-of-day decisions (postponing the trip to a later moment) are common practice: more than one person out of two appears to postpone his/her trip in the presence of snow. Next to the timing of the trip, also the route taken is considered to be changed by almost half of the respondents. This major impact of snow on travel behavior is also revealed on the network. Take as an example Hanbali and Kuemmel (*18*) who found traffic volume reductions on highways away from the major urban centers in the United States ranging from 7% to 56 depending on the intensity of the snowfall.

Extreme temperatures (both cold and warm temperatures) appear to have the least impact on commuting behavior, while storms, fog and heavy rain appear to have an effect mainly on the timing of the trip: people appear to postpone their trips until more favorable weather conditions apply.

When the focus is turned to behavioral changes, it is immediately clear that the work/school location is the least frequently changed. Obviously the main reason is the fact that the locations of work and school sites are relatively fixed. Nonetheless, telecommuting alternatives, satellite offices and e-learning are opportunities making location changes feasible. The most prevalent changes in commuting behavior are changes in the timing of the trip and changes in the route chosen. A possible reason is the fact that people are trying to avoid traffic jams by diverging the paths and departure times of their trips.

TABLE 2 Frequencies of Changes in Work/School Trips due to Weather

Change	Frequency	Cold	Snow	Rain	Fog	Warm	Storm
Mode Change	Never	93.8%	75.8%	84.8%	94.6%	81.6%	86.8%
	1-25%	4.4%	14.6%	7.9%	3.7%	10.5%	8.1%
	26-50%	0.9%	2.6%	1.4%	0.1%	4.4%	0.9%
	>50%	0.9%	7.0%	5.9%	1.6%	3.5%	4.2%
Time-of-day Change	Never	89.5%	47.8%	70.3%	74.0%	94.4%	74.9%
	1-25%	6.0%	23.7%	17.0%	13.7%	2.8%	14.9%
	26-50%	2.5%	9.2%	6.9%	6.9%	1.5%	4.7%
	>50%	2.0%	19.3%	5.8%	5.4%	1.3%	5.5%
Location Change	Never	96.6%	86.6%	94.4%	97.5%	97.0%	93.3%
	1-25%	2.2%	8.4%	3.3%	1.3%	2.0%	4.1%
	26-50%	0.6%	3.0%	1.0%	0.5%	0.8%	1.1%
	>50%	0.6%	2.0%	1.3%	0.7%	0.2%	1.5%
Trip Cancellation	Never	96.2%	75.4%	93.8%	95.3%	89.0%	92.6%
	1-25%	3.4%	19.4%	5.0%	4.3%	10.1%	6.1%
	26-50%	0.4%	4.1%	0.2%	0.4%	0.9%	0.7%
	>50%	0.0%	1.1%	1.0%	0.0%	0.0%	0.6%
Route Change	Never	90.5%	56.4%	85.0%	85.4%	96.4%	87.1%
	1-25%	6.3%	26.7%	9.9%	10.0%	2.4%	8.4%
	26-50%	1.8%	9.8%	2.5%	1.5%	0.9%	2.7%
	>50%	1.4%	7.1%	2.6%	3.1%	0.3%	1.8%

3.2 Changes in Shopping Trips

The percentages of respondents making a certain travel behavior change for shopping trips are displayed in Table 3. Similarly to commuting trips, the most marked finding from the comparison of the different weather conditions is the fact that snow has the largest impact on shopping trips. Especially time-of-day changes (trip postponements) and trip cancellations are standard: about 70% of the respondents postpone their shopping trip, and the same percentage even cancels their shopping trip.

Next to the effect of snow, also the effects of heavy rain, and heavy winds/storms are very striking: about 60% of the respondents postpone and around half of them cancel their shopping trips during periods of heavy rain, and slightly less pronounced about half of the respondents postpone their shopping trips during stormy periods, while 45% cancels their shopping trips.

The comparison of extreme temperatures provides the insight that more people change their transport mode for shopping trips during warm temperatures (above 28° C), than during cold temperatures (below freezing). One explanation could be that people are more enticed to use slow modes (walking, cycling) during highly favorable weather conditions. This is line with the results of Bos (*5*) who found an increase in bicycle use during warm summers.

The most prevalent changes in shopping related travel behavior are trip postponements and trip cancellations. Extreme weather conditions appear to cause serious changes in the activities people want to perform. When the overall results of shopping trips are compared with commuting trips, a considerable larger percentage of people changes their shopping-related travel behavior than their commuting behavior. This can be explained by the fact that it is much easier to postpone/cancel shopping activities as opposed to work/school-related activities, which is also observed on the Flemish highway network (*13*).

TABLE 3 Frequencies of Changes in Shopping Trips due to Weather

Change	Frequency	Cold	Snow	Rain	Fog	Warm	Storm
Mode Change	Never	91.5%	78.2%	85.6%	91.9%	79.7%	86.8%
	1-25%	5.2%	11.2%	6.0%	4.4%	10.2%	6.5%
	26-50%	1.4%	3.4%	2.2%	0.8%	4.9%	1.6%
	>50%	1.9%	7.2%	6.2%	2.9%	5.2%	5.1%
Time-of-day Change	Never	80.2%	29.4%	41.8%	59.9%	80.0%	47.7%
	1-25%	13.1%	28.2%	24.1%	19.2%	13.0%	22.8%
	26-50%	3.9%	16.9%	13.6%	11.4%	4.2%	13.7%
	>50%	2.8%	25.5%	20.5%	9.5%	2.8%	15.8%
Location Change	Never	86.8%	54.0%	68.4%	72.2%	83.7%	69.3%
	1-25%	7.4%	20.6%	12.6%	11.9%	10.5%	13.7%
	26-50%	2.8%	9.4%	10.7%	8.8%	2.6%	10.0%
	>50%	3.0%	16.0%	8.3%	7.1%	3.2%	7.0%
Trip Cancellation	Never	86.7%	31.9%	48.4%	64.4%	82.6%	55.0%
	1-25%	7.1%	33.7%	29.3%	20.4%	13.3%	23.3%
	26-50%	3.0%	14.5%	11.6%	8.8%	2.7%	11.6%
	>50%	3.2%	19.9%	10.7%	6.4%	1.4%	10.1%
Route Change	Never	93.1%	58.8%	81.7%	80.6%	93.3%	81.7%
	1-25%	4.5%	23.2%	11.0%	11.3%	4.7%	10.7%
	26-50%	1.4%	10.3%	3.7%	4.8%	0.5%	4.6%
	>50%	1.0%	7.7%	3.6%	3.3%	1.5%	3.0%

3.3 Changes in Leisure Trips

For the final category of trips that were considered, namely leisure trips, the percentages of respondents making a certain travel behavior change are shown in Table 4. Yet again snowy weather has the largest impact. Similar to shopping trips, trip postponements and trip cancellations are the most frequent change in travel behavior: about 65% of the respondents postpone their leisure trip, and the same number cancels their leisure trip.

Apart from the effect of snow, heavy rain and heavy wind/storms are also clearly influencing leisure-related travel behavior: about 45% of the respondents postpone and a similar percentage cancels their leisure trips during periods of heavy rain or periods with heavy wind. The effect of extreme temperature on leisure trips is very similar to the effect on shopping trips: more people alter their transport mode for leisure trips during warm temperatures, than during cold temperatures. The resemblances between shopping and leisure trips are further underlined when the most prevalent changes in leisure trips are discussed: trip postponements and trip cancellations are also the most frequent performed changes in leisure related travel behavior. The homogeneity between the behavioral changes concerning and leisure trips and shopping trips can be explained by the fact that both leisure and shopping activities are non-obligatory activities, which are in general more flexible (more easy to postpone/advance or cancel) than obligatory activities such as school and work.

TABLE 4 Frequencies of Changes in Leisure Trips due to Weather

Change	Frequency	Cold	Snow	Rain	Fog	Warm	Storm
Mode Change	Never	89.9%	74.4%	83.9%	87.3%	77.3%	85.6%
	1-25%	7.7%	13.5%	8.9%	8.1%	11.7%	8.7%
	26-50%	1.2%	3.8%	3.1%	3.5%	6.4%	3.0%
	>50%	1.2%	8.3%	4.1%	1.1%	4.6%	2.7%
Time-of-day Change	Never	85.3%	35.1%	54.3%	61.8%	85.3%	58.6%
	1-25%	10.5%	30.9%	26.1%	21.3%	11.5%	20.1%
	26-50%	2.0%	15.0%	12.7%	9.2%	2.0%	13.0%
	>50%	2.2%	19.0%	6.9%	7.7%	1.2%	8.3%
Location Change	Never	83.3%	70.9%	75.1%	81.5%	83.9%	74.1%
	1-25%	9.9%	14.1%	11.3%	9.3%	10.0%	13.1%
	26-50%	2.8%	6.5%	6.3%	5.3%	3.3%	6.5%
	>50%	4.0%	8.5%	7.3%	3.9%	2.8%	6.3%
Trip Cancellation	Never	79.3%	35.6%	56.1%	66.1%	82.2%	55.3%
	1-25%	14.4%	34.0%	24.2%	20.2%	13.9%	23.5%
	26-50%	4.1%	13.8%	9.6%	8.0%	3.0%	12.1%
	>50%	2.2%	16.6%	10.1%	5.7%	0.9%	9.1%
Route Change	Never	92.8%	55.1%	76.4%	78.6%	94.3%	76.9%
	1-25%	4.4%	24.4%	13.9%	13.5%	3.6%	12.4%
	26-50%	2.1%	11.9%	5.9%	4.5%	1.2%	6.9%
	>50%	0.7%	8.6%	3.8%	3.4%	0.9%	3.8%

4 STATISTICAL ANALYSIS OF THE CHANGES IN TRAVEL BEHAVIOR

The descriptive results in the previous section gave a clear indication that changes in travel behavior in response to weather conditions are dependent on the type of weather condition. Moreover, the results suggested that the behavioral changes were strongly dependent on the underlying activity. In this section, these two hypotheses are formally tested using Pearson chi-square independence tests. First, the statistical analysis of the hypothesis that the type of weather determines the likelihood of a change in travel behavior is provided. Afterwards, an elaboration on the test of the hypothesis that changes in travel behavior due to weather conditions are dependent on the trip purpose is given. Note that multiple testing is accounted for by lowering the significance level in a Bonferroni-like approach.

4.1 Dependence of Changes in Travel Behavior on Type of Weather

For each activity (trip purpose), the dependency between the change in travel behavior and the type of weather was formally tested. Table 5 shows the chi-square values, degrees of freedom (DF) and corresponding significance levels of the different tests. First, for each activity, the dependency between all travel behavior changes and weather conditions was tested. Afterwards, the dependencies of the specific travel behavior changes and weather conditions were assessed.

A first conclusion that can be drawn from Table 5 is the fact that all behavioral changes highly depend on the type of weather (the null hypothesis of independence is rejected for all behavioral changes with a p-value smaller than 0.001). Similar to the preliminary conclusions drawn from the descriptive results, for work/school-related trips, trip postponement (time-of-day change) and route changes are the strongest depending on the weather type, while for shopping and leisure trips, the relationship is the most significant (higher chi²-value, same degrees of freedom) for trip postponements and trip cancellations. Although highly significant (p-value smaller than 0.001) the interdependence between changes in travel behavior and type of weather was smallest for location and mode changes.

Recall that the number of degrees of freedom is calculated by multiplying the number of rows minus one by the numb of columns minus one. For the dependence of specific travel behavior changes on weather conditions the independence test followed a chi-square distribution with 15 degrees of freedom: 4 frequencies (the number of people who would never change their behavior, and respectively the ones that change their behavior in 1-25%, 26-50% and more than 50% of the cases) minus one multiplied by 6 weather conditions minus one. Since the underlying assumption of the independence test (minimum 80% of the cells expected counts should be at least equal to 5) was not fulfilled for the hypothesis test that assessed the relationship between trip cancellations of commuting trips and weather conditions, an alternative independence test was tabulated by combining the three categories of people that change their behavior. As a result the number of degrees of freedom for this test was smaller than for the other test, as could be noticed from Table 5.

TABLE 5 Dependence of Behavioral Changes on Weather

Trip Purpose	Behavioral Change	Chi²	DF	Signif. [1]	Cramer's V
Work/School	All Changes	1185.75	95	***	0.125
	Mode Change	138.71	15	***	0.123
	Time-of-day Change	409.05	15	***	0.212
	Location Change	81.12	15	***	0.094
	Trip Cancellation [2]	174.79	5	***	0.240
	Route Change	362.56	15	***	0.199
Shopping	All	1728.89	95	***	0.142
	Mode Change	92.24	15	***	0.095
	Time-of-day Change	542.97	15	***	0.230
	Location Change	235.69	15	***	0.152
	Trip Cancellation	555.65	15	***	0.233
	Route Change	302.34	15	***	0.172
Leisure	All	1456.24	95	***	0.130
	Mode Change	107.92	15	***	0.102
	Time-of-day Change	522.45	15	***	0.224
	Location Change	62.85	15	***	0.078
	Trip Cancellation	405.26	15	***	0.197
	Route Change	357.76	15	***	0.185

[1] Significance: * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001
[2] Estimated using reduced answer possibilities (Yes/No)

4.2 Dependence of Changes in Travel Behavior on Trip Purpose

To test the dependence of changes in travel behavior on activity type (trip purpose), first independence tests are performed on an aggregate level (aggregation over all travel behavior changes). Table 6 displays the chi-square values, degrees of freedom (DF) and corresponding significance levels of these tests.

In line with the tests assessing the dependence of changes in travel behavior on the type of weather, also for the dependence of changes in travel behavior on trip purpose confirm the preliminary conclusions drawn from the descriptive results: the extent to which people adapt their travel behavior is strongly dependent (all p-values smaller than 0.001) on the trip purpose. This dependence appears to be the largest for periods of heavy rain, snow and heavy wind. For extreme temperatures this dependency appears to be smaller (lower chi-square value and same number of degrees of freedom), yet still highly significant.

TABLE 6 Dependence of Behavioral Changes on Trip Purpose (Aggregate Level)

Weather	Behavioral Change	Chi²	DF	Signif. [1]	Cramer's V
All Types	All Changes	2180.35	238	***	0.148
Cold	All Changes	165.69	38	***	0.100
Snow	All Changes	473.46	38	***	0.169
Rain	All Changes	550.80	38	***	0.183
Fog	All Changes	382.66	38	***	0.152
Warm	All Changes	144.80	38	***	0.094
Storm	All Changes	462.94	38	***	0.167

[1] Significance: * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001

In order to further investigate the dependence of the changes in travel behavior on trip purpose a more detailed analysis is performed: for all six weather conditions, the dependence of the specific behavioral changes on trip purpose was investigated. Different conclusions could be drawn from this disaggregate analysis. First, one could note that for all weather conditions time-of-day changes (trip postponements), location changes and trip cancellations were significantly depending on trip purpose (p-values all smaller than 0.01 and for location changes even all smaller than 0.001). In addition, all behavioral changes in response to fog and heavy wind/storm were statistically significantly depending on the trip purpose (p-values all smaller than 0.05).

A thorough look at the effect of cold and warm weather, as well as snow, provides the insight that the extents to which people change their mode or route in response to these weather conditions are not depending on the trip purpose. Furthermore, inspection of Table 7 reveals that for all weather conditions (except warm weather) the highest dependency of behavioral changes on trip purpose was found for trip cancellations. A possible explanation for this contrast with warm weather conditions is the fact that all other weather conditions are considered to be unfavorable weather conditions, whereas high temperatures may be considered as favorable, at least for some part of the population.

5 CONCLUSIONS

In this study the hypothesis of dependence of changes in travel behavior on type of weather on the one hand, and the hypothesis of dependence of changes in travel behavior on trip purpose (activity type) on the other hand were formally tested. Both the results from the descriptive analysis and the Pearson chi-square independence tests confirmed that indeed the type of weather condition matters, and that the changes in travel behavior in response to these weather conditions are highly dependent on the trip purpose.

TABLE 7 Dependence of Behavioral Changes on Trip Purpose (Disaggregate Level)

Weather	Behavioral change	Chi²	DF	Signif. [1]	Cramer's V
Cold	Mode Change	9.03	6	n.s.	0.052
	Time-of-day Change	21.24	6	**	0.080
	Location Change	50.88	6	***	0.124
	Trip Cancellation	79.41	6	***	0.155
	Route Change	5.12	6	n.s.	0.039
Snow	Mode Change	5.07	6	n.s.	0.039
	Time-of-day Change	49.55	6	***	0.122
	Location Change	143.46	6	***	0.208
	Trip Cancellation	271.33	6	***	0.287
	Route Change	4.06	6	n.s.	0.035
Rain	Mode Change	9.93	6	n.s.	0.055
	Time-of-day Change	129.11	6	***	0.198
	Location Change	120.21	6	***	0.191
	Trip Cancellation	275.88	6	***	0.289
	Route Change	15.68	6	*	0.069
Fog	Mode Change	42.05	6	***	0.113
	Time-of-day Change	30.06	6	***	0.095
	Location Change	126.67	6	***	0.196
	Trip Cancellation	170.08	6	***	0.227
	Route Change	13.80	6	*	0.065
Warm	Mode Change	5.41	6	n.s.	0.040
	Time-of-day Change	54.24	6	***	0.128
	Location Change	58.03	6	***	0.133
	Trip Cancellation [2]	11.59	2	**	0.059
	Route Change [2]	5.15	2	n.s.	0.039
Storm	Mode Change	13.15	6	*	0.063
	Time-of-day Change	97.85	6	***	0.172
	Location Change	104.97	6	***	0.178
	Trip Cancellation	225.54	6	***	0.261
	Route Change	21.42	6	**	0.081

[1] Significance: * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001, n.s.: not significant
[2] Estimated using reduced answer possibilities (Yes/No)

While the majority of the papers in international literature focus on traffic safety and traffic flows, this paper contributes to the literature by looking at the actual underlying travel behavior by means of a multifaceted stated adaptation approach. The clear dependence of behavioral adjustments on activities (trip purposes) provides policy makers with a deeper understanding of how weather conditions affect traffic. The value of this contribution is stressed by weather related policy issues such as increased fuel consumption, economic losses due to traffic delays, and higher traffic counts.

The findings in this paper are consonant with international literature and provide a solid base for the further analysis of weather-related policy measures, such as for instance the examination whether extreme weather conditions cause last minute changes in travel mode and the assessment whether high quality bus shelters do make differences in last minute mode changes. Further generalizations of the findings are possible by shifting the scope towards revealed travel behavior and by braking down the modal changes to different transport modes. Triangulation of both stated and revealed travel behavior on the one hand, and traffic intensities on the other hand, is certainly a key challenge for further research.

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