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Changes in Travel Behavior in Response to Weather Conditions Do Type of Weather and Trip Purpose Matter? Peer-reviewed author version

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

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Weather events can affect traffic in various ways; it can influence travel demand, traffic flows 3 and traffic safety. This paper focuses on the impact of weather conditions on travel demand. The 4 main objectives of this paper are to test the hypothesis that the type of weather determines the 5 likelihood of a change in travel behavior and to assay whether the changes in travel behavior due 6 to weather conditions are dependent on the trip purpose. To this end, a stated adaptation study 7 was conducted in Flanders (Dutch speaking region of Belgium). In total 586 respondents 8 completed the survey, which was administered both on the Internet and via a traditional paper-9 and-pencil questionnaire. To ensure an optimal correspondence between the survey sample 10 composition and the Flemish population, the observations in the sample are weighted. To test the 11 main hypotheses Pearson chi-square independence tests will be performed. Both the results from 12 the descriptive analysis and the independence tests confirm that the type of weather matters, and 13 that the changes in travel behavior in response to these weather conditions are highly dependent 14 on the trip purpose. This dependence of behavioral adjustments on trip purposes provides policy 15 makers with a deeper understanding of how weather conditions affect traffic. Further 16 generalizations of the findings are possible by shifting the scope towards revealed travel 17 behavior. Triangulation of both stated and revealed travel behavior on the one hand, and traffic 18 19 intensities on the other hand, is certainly a key challenge for further research.

1 BACKGROUND

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A deeper understanding of how various weather conditions affect traffic is essential for policy 3 makers. This is stressed by policy issues which are often related with adverse weather events 4 such as increased fuel consumption, economic losses due to traffic delays, and higher traffic 5 counts. At network level, adverse weather events increase the uncertainty in system 6 performance, resulting for instance in a network capacity reduction ranging from 10 to 20% in 7 heavy rain (1). Maze et al. (2) reported that weather events affect three predominant traffic 8 variables: travel demand, traffic safety and the traffic flow relationship. This paper focuses on 9 10 the impact of weather on travel demand.

Weather can influence travel demand in different ways, including diversions of trips to 11 other modes or other paths, or even cancellations of trips (2). Day-to-day weather conditions 12 such as fog and precipitation can decrease travel demand, for instance when drivers postpone or 13 cancel discretionary activities (e.g. leisure activities), but can also have an increasing effect 14 when travel modes are shifted from slow modes (walking, cycling) towards motorized vehicles 15 (3). Mode changes, changes in departure time and diversions to alternate route, were reported by 16 Khattak and De Palma (4) as the most prevalent behavioral adaptations. Bos (5) indicated that in 17 the Netherlands heavy rain reduces the number of cyclists, whereas mild winters and warm 18 19 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 20 passenger). A similar result was found by Nankervis (7), who examined the effect of both (short-21 term) weather conditions and (long-term) seasonal variation patterns on bicycle commuting 22 patterns among students in the temperate climate of Melbourne, Australia: cycle commuting was 23 affected by long-term, climatic conditions as well as daily weather conditions. According to Guo 24 et al. (8) temperature, rain, snow and wind all influence transit ridership of the Chicago Transit 25 Authority: good weather increases ridership, while bad weather has a diminishing effect. Guo et 26 al. (8) also stressed that next to transit ridership, also vehicle running and dwell times, as well as 27 the cost of operation, are affected by weather. In Brussels (Belgium) on the other hand, the 28 transit agency reported higher levels of transit ridership during adverse weather (4). 29

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

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2.1 A Stated Adaptation Approach

The data needed to address the main research questions were collected by means of a stated 5 adaptation experiment. Different definitions about stated adaptation experiments can be found in 6 literature (9,10). In this paper, stated adaptation experiments are regarded as an alternative to the 7 more widely used stated preference and choice experiments. The main difference between stated 8 adaptation and stated preference and choice experiments is the task posed to the respondents. In 9 stated preference experiments, respondents are requested to indicate their preference to 10 sequentially presented attribute profiles. In stated choice experiments, respondents are shown 11 choice sets of two or more attribute profiles and are asked to choose the profile they like best (or 12 alternatively allocate some fixed budget among the profile). In stated adaptation experiments, 13 respondents are asked to indicate if and how they would change their behavior considering 14 experimentally varied attribute profiles, typically representing scenarios, in this paper the 15 different weather conditions. 16

In total 586 respondents completed the stated adaptation survey, which was administered 17 both on the Internet (13.3%) and via a traditional paper-and-pencil questionnaire (86.7%). The 18 choice for this dual mode administration was made to remedy the sample bias that is introduced 19 when only an internet-based data collection is conducted. After all, previous studies have 20 demonstrated that some socio-economic classes of society, like older-age and lower-education 21 groups, may be more reluctant towards using computer-assisted instruments for the data 22 collection (11,12). In total 90 behavioral adaptations in response to different weather conditions 23 were queried; the frequencies of 5 travel behavior changes in response to 6 weather conditions 24 were surveyed, and this was repeated for 3 types of trips. An elaboration on these different items 25 will be provided in the following subsections. 26

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2.1.1 Weather Conditions

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The following weather conditions were considered: cold temperature (defined as temperatures 30 below freezing (0° C, 32° F), abbreviated as 'cold'), warm temperature (defined as temperatures 31 above 28° C (82.4° F), abbreviated as 'warm'), snow/freezing rain, heavy rain/thunderstorm 32 (abbreviated as 'rain'), fog and storm/heavy wind. Note that Cools et al. (13) reported that these 33 weather conditions had a significant impact on daily traffic intensities measured on Belgian 34 highways. Therefore, the decision was made to analyze the impact of these weather conditions 35 on the underlying travel behavior. To provide a better understanding of how frequent these 36 weather events occur, various weather-related measures are provided in Table 1. In addition, it is 37 noteworthy to mention that in general, Flanders has a moderate maritime climate. 38

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 $< 0^{\circ}$ C)	27.0	37.0	47.0
Number of wintry days (max $< 0^{\circ}$ 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 $\geq 30^{\circ}$ 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 (>= $0,1 \text{ mm}$)	204.0	209.0	207.0
Number of days with thunderstorm	94.0	95.0	94.0

TABLE 1 Weather Parameters measured in Uccle¹ (nearby Brussels, Belgium)

2 ¹ Source: Royal Meteorological Institute of Belgium (14)

² Normal: long-term meteorological average (1971-2000)

5 2.1.2 Changes in Travel Behavior

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The stated adaptation questionnaire was subdivided into three parts, corresponding to the three 7 8 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 9 10 (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 11 (never, in 1-25% of the cases, in 26-50% of the cases, or in more than 50% of the cases) they 12 make a certain change in travel behavior for each of the six weather conditions. The following 13 changes in travel behavior were queried: (i) a change in transport mode, (ii) a change in timing 14 of the trip (postponement/advancing of the trip to a later/earlier moment on the same day), (iii) a 15 change in the location where the activity (work/school, shopping or leisure) will be performed, 16 (iv) elimination of the trip by skipping the activity (trip cancellation), and (v) a change in the 17 route of the trip. To illustrate the questionnaire style, Figure 1 displays the question concerning 18 19 the postponement/advancing of work/school-related trips to a later/earlier moment the same day. 20

Do you <u>postpone</u> or <u>advance</u> 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	0	0	O Í	O É		
Snow/freezing rain	0	0	0	0		
Heavy rain/thunderstorm	0	0	0	0		
Fog	0	0	0	0		
Warm temperature	0	0	0	0		
Storm/heavy wind	0	0	0	0		

FIGURE 1 Stated adaptation question concerning postponement/advancing work/schoolrelated trip.

3 4

5 2.2 Statistical Analyses

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In order to guarantee an optimal correspondence between the survey sample composition and the 7 Flemish population, the observations in the sample are weighted. The weights were calculated 8 by matching the marginal distributions of the sample with the marginal distributions of the 9 population. Age, gender and civil state were the basis for this matching process. Recall that the 10 main objectives of this paper are to test the hypothesis that the type of weather determines the 11 likelihood of a change in travel behavior and to assay whether the changes in travel behavior due 12 13 to weather conditions are associated with the type of trip. To test these hypotheses, independence tests will be performed. 14

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:

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

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:

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

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).

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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.

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17 **3.1 Changes in Commuting Trips**

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For the commuting (work/school) trips, the percentages of respondents making a certain travel 19 behavior change are displayed in Table 2. When the different weather conditions are compared, 20 it is immediately clear that snow has the largest impact on commuting trips. Especially time-of-21 day decisions (postponing the trip to a later moment) are common practice: more than one 22 23 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 24 major impact of snow on travel behavior is also revealed on the network. Take as an example 25 Hanbali and Kuemmel (18) who found traffic volume reductions on highways away from the 26 major urban centers in the United States ranging from 7% to 56 depending on the intensity of the 27 snowfall. 28

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.

Change	Frequency	Cold	Snow	Rain	Fog	Warm	Storm
	Never	93.8%	75.8%	84.8%	94.6%	81.6%	86.8%
Mode	1-25%	4.4%	14.6%	7.9%	3.7%	10.5%	8.1%
Change	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%
	Never	89.5%	47.8%	70.3%	74.0%	94.4%	74.9%
Time-of-day	1-25%	6.0%	23.7%	17.0%	13.7%	2.8%	14.9%
Change	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%
	Never	96.6%	86.6%	94.4%	97.5%	97.0%	93.3%
Location	1-25%	2.2%	8.4%	3.3%	1.3%	2.0%	4.1%
Change	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%
	Never	96.2%	75.4%	93.8%	95.3%	89.0%	92.6%
Trip	1-25%	3.4%	19.4%	5.0%	4.3%	10.1%	6.1%
Cancellation	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%
	Never	90.5%	56.4%	85.0%	85.4%	96.4%	87.1%
Route	1-25%	6.3%	26.7%	9.9%	10.0%	2.4%	8.4%
Change	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%

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

3.2 Changes in Shopping Trips

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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.

11 Next to the effect of snow, also the effects of heavy rain, and heavy winds/storms are 12 very striking: about 60% of the respondents postpone and around half of them cancel their 13 shopping trips during periods of heavy rain, and slightly less pronounced about half of the 14 respondents postpone their shopping trips during stormy periods, while 45% cancels their 15 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 1 easier to postpone/cancel shopping activities as opposed to work/school-related activities, which

2 is also observed on the Flemish highway network (13).

3

Change	Frequency	Cold	Snow	Rain	Fog	Warm	Storm
	Never	91.5%	78.2%	85.6%	91.9%	79.7%	86.8%
Mode	1-25%	5.2%	11.2%	6.0%	4.4%	10.2%	6.5%
Change	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%
	Never	80.2%	29.4%	41.8%	59.9%	80.0%	47.7%
Time-of-day	1-25%	13.1%	28.2%	24.1%	19.2%	13.0%	22.8%
Change	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%
	Never	86.8%	54.0%	68.4%	72.2%	83.7%	69.3%
Location	1-25%	7.4%	20.6%	12.6%	11.9%	10.5%	13.7%
Change	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%
	Never	86.7%	31.9%	48.4%	64.4%	82.6%	55.0%
Trip	1-25%	7.1%	33.7%	29.3%	20.4%	13.3%	23.3%
Cancellation	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%
	Never	93.1%	58.8%	81.7%	80.6%	93.3%	81.7%
Route	1-25%	4.5%	23.2%	11.0%	11.3%	4.7%	10.7%
Change	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%

4 TABLE 3 Frequencies of Changes in Shopping Trips due to Weather

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3.3 Changes in Leisure Trips

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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 13 influencing leisure-related travel behavior: about 45% of the respondents postpone and a similar 14 percentage cancels their leisure trips during periods of heavy rain or periods with heavy wind. 15 The effect of extreme temperature on leisure trips is very similar to the effect on shopping trips: 16 17 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 18 when the most prevalent changes in leisure trips are discussed: trip postponements and trip 19 cancellations are also the most frequent performed changes in leisure related travel behavior. 20 The homogeneity between the behavioral changes concerning and leisure trips and shopping 21 trips can be explained by the fact that both leisure and shopping activities are non-obligatory 22 activities, which are in general more flexible (more easy to postpone/advance or cancel) than 23 obligatory activities such as school and work. 24

Change	Frequency	Cold	Snow	Rain	Fog	Warm	Storm
	Never	89.9%	74.4%	83.9%	87.3%	77.3%	85.6%
Mode	1-25%	7.7%	13.5%	8.9%	8.1%	11.7%	8.7%
Change	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%
	Never	85.3%	35.1%	54.3%	61.8%	85.3%	58.6%
Time-of-day	1-25%	10.5%	30.9%	26.1%	21.3%	11.5%	20.1%
Change	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%
	Never	83.3%	70.9%	75.1%	81.5%	83.9%	74.1%
Location	1-25%	9.9%	14.1%	11.3%	9.3%	10.0%	13.1%
Change	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%
	Never	79.3%	35.6%	56.1%	66.1%	82.2%	55.3%
Trip	1-25%	14.4%	34.0%	24.2%	20.2%	13.9%	23.5%
Cancellation	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%
	Never	92.8%	55.1%	76.4%	78.6%	94.3%	76.9%
Route	1-25%	4.4%	24.4%	13.9%	13.5%	3.6%	12.4%
Change	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%

1 TABLE 4 Frequencies of Changes in Leisure Trips due to Weather

4 STATISTICAL ANALYSIS OF THE CHANGES IN TRAVEL BEHAVIOR

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5 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. 6 Moreover, the results suggested that the behavioral changes were strongly dependent on the 7 underlying activity. In this section, these two hypotheses are formally tested using Pearson chi-8 square independence tests. First, the statistical analysis of the hypothesis that the type of weather 9 determines the likelihood of a change in travel behavior is provided. Afterwards, an elaboration 10 on the test of the hypothesis that changes in travel behavior due to weather conditions are 11 dependent on the trip purpose is given. Note that multiple testing is accounted for by lowering 12 the significance level in a Bonferroni-like approach. 13

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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 6 rows minus one by the numb of columns minus one. For the dependence of specific travel 7 behavior changes on weather conditions the independence test followed a chi-square distribution 8 with 15 degrees of freedom: 4 frequencies (the number of people who would never change their 9 10 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 11 12 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 13 trip cancellations of commuting trips and weather conditions, an alternative independence test 14 was tabulated by combining the three categories of people that change their behavior. As a result 15 the number of degrees of freedom for this test was smaller than for the other test, as could be 16 noticed from Table 5. 17

Trip Purpose **Behavioral Change** Chi² DF Signif. Cramer's V *** 95 All Changes 1185.75 0.125 *** Mode Change 15 0.123 138.71 *** Time-of-day Change 409.05 15 0.212 Work/School Location Change 15 *** 0.094 81.12 5 Trip Cancellation² *** 174.79 0.240 15 *** Route Change 362.56 0.199 95 *** 0.142 All 1728.89 *** Mode Change 92.24 15 0.095 Time-of-day Change 542.97 15 *** 0.230 Shopping Location Change *** 15 235.69 0.152 *** Trip Cancellation 15 555.65 0.233 15 *** Route Change 302.34 0.172 95 *** 0.130 All 1456.24 *** 15 Mode Change 107.92 0.102 Time-of-day Change 15 *** 0.224 522.45 Leisure *** Location Change 15 0.078 62.85 0.197 Trip Cancellation 405.26 15 *** Route Change 357.76 *** 0.185 15 ¹ Significance: * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001 ² Estimated using reduced answer possibilities (Yes/No)

19 **TABLE 5 Dependence of Behavioral Changes on Weather**

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23 **4.2 Dependence of Changes in Travel Behavior on Trip Purpose**

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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.

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

Weather	Behavioral Change	Chi ²	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					

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14 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 15 the specific behavioral changes on trip purpose was investigated. Different conclusions could be 16 drawn from this disaggregate analysis. First, one could note that for all weather conditions time-17 of-day changes (trip postponements), location changes and trip cancellations were significantly 18 depending on trip purpose (p-values all smaller than 0.01 and for location changes even all 19 smaller than 0.001). In addition, all behavioral changes in response to fog and heavy wind/storm 20 21 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 22 insight that the extents to which people change their mode or route in response to these weather 23 conditions are not depending on the trip purpose. Furthermore, inspection of Table 7 reveals that 24 for all weather conditions (except warm weather) the highest dependency of behavioral changes 25 on trip purpose was found for trip cancellations. A possible explanation for this contrast with 26 warm weather conditions is the fact that all other weather conditions are considered to be 27 unfavorable weather conditions, whereas high temperatures may be considered as favorable, at 28 least for some part of the population. 29

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31 **5 CONCLUSIONS**

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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.

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

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

2 ¹ Significance: * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001, n.s.: not significant

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5 While the majority of the papers in international literature focus on traffic safety and traffic 6 flows, this paper contributes to the literature by looking at the actual underlying travel behavior 7 by means of a multifaceted stated adaptation approach. The clear dependence of behavioral 8 adjustments on activities (trip purposes) provides policy makers with a deeper understanding of 9 how weather conditions affect traffic. The value of this contribution is stressed by weather 10 related policy issues such as increased fuel consumption, economic losses due to traffic delays, 11 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

² Estimated using reduced answer possibilities (Yes/No)

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

- 3 on the other hand, is certainly a key challenge for further research.
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