**Transit Information Utilization during an Extreme Weather Event:
An Analysis of Smartphone App Data**

Word Count: 5,352 (text) + 250 * 7 (figures) = 7,102

Submission Date: November 15, 2017

Coline Remy
Ecole Nationale des Travaux Publics de l'Etat
3 Rue Maurice Audin, Vaulx-en-Velin cedex, 69518, France
Email: coline.remy@entpe.fr
Phone: +33665157972

Candace Brakewood (Corresponding Author)
University of Tennessee
320 John D. Tickle Building, 851 Neyland Drive, Knoxville, TN 37996
Email: cbrakewo@utk.edu
Phone: +1-(865)-974-7706

Niloofar Ghahramani
The City College of New York
160 Convent Avenue, New York, NY, 10031
Email: nghahra000@citymail.cuny.edu
Phone: +1-(702)-690-1809

Jonathan Peters
The College of Staten Island
Room 3N-220, 2800 Victory Blvd., Staten Island, NY 10314
Email: Jonathan.Peters@csi.cuny.edu
Phone: +1-(718)-982-2958

Eunjin Kwak
The College of Staten Island (Former Affiliation)
2800 Victory Blvd., Staten Island, NY 10314
Email: Eunjin.Kwak@cix.csi.cuny.edu

Remy, Brakewood, Ghahramani, Kwak & Peters

1 **ABSTRACT**
2 Extreme weather events such as heavy snow can severely disrupt urban transportation systems.
3 When this occurs, travelers often seek information about the status of transportation services. This
4 study aims to assess information utilization during an extreme weather event by analyzing data
5 from a smartphone application ("app") called Transit, which provides real-time transit and shared
6 mobility information in many cities. This research focuses on a snowstorm that hit the northeastern
7 USA in January 2016 and severely disrupted transit and shared mobility services. An analysis of
8 Transit app data is conducted in four parts for New York City, Philadelphia, and Washington, D.C.
9 First, hourly app utilization during the snowstorm is compared to mean hourly app utilization prior
10 to the storm. Second, the rate of app usage is calculated by dividing hourly utilization during the
11 storm by the mean hourly volume before the storm. Third, an ordinary least squares regression
12 model of hourly app usage was estimated for each city. Last, a feature within the app used to
13 request Uber vehicles was examined. The results of the first three analyses reveal that overall app
14 usage decreased during the snowstorm in all three cities; after the storm, New York experienced a
15 significant increase in overall app use during the first Monday commuting period. The analysis of
16 Uber data reveals that app users continued to search for ridehailing services during the snowstorm,
17 despite travel bans. These findings are important for transportation operators and app developers
18 to understand how travelers use information during extreme weather events.

Remy, Brakewood, Ghahramani, Kwak & Peters

1 **INTRODUCTION**
2 Extreme weather events such as heavy snow can severely disrupt urban transportation systems.
3 One recent example occurred in January 2016, when Winter Storm Jonas dumped historic amounts
4 of snow throughout the northeastern region of the United States. Jonas was the single largest
5 snowstorm on record for numerous locations in the northeast, including New York City's
6 LaGuardia Airport and Baltimore-Washington International Airport (*1*). This historic snowfall
7 deeply affected the transportation systems in New York City (NYC), Philadelphia (PHI), and
8 Washington, D.C. (DC). The local governments declared travel bans, public transit systems were
9 shut down, and the period of recovery in some areas lasted for nearly a week after the snowstorm.
10   When extreme weather events such as Winter Storm Jonas occur, travelers often seek
11 information about the status of transportation services to determine if they are shut down and to
12 stay informed as they reopen. However, understanding how travelers seek information during
13 extreme events can be challenging due to a lack of readily available data. For example, surveys
14 are difficult to administer during unplanned events, and they can be expensive to collect
15 retroactively. Therefore, this research aims to use a new data source to understand how travelers
16 seek information during an extreme weather event. Specifically, the records from an urban
17 transportation information smartphone application (or "app") are examined to provide insight into
18 how travelers utilize new information and communication technologies during severe storms.
19
20 **PRIOR RESEARCH AND OBJECTIVES**
21 There is a growing body of literature that examines the transportation system impacts of extreme
22 weather events (e.g., *2*, *3*, *4*) and large special events such as sports games *(*e.g., *5, 6).* This brief
23 review of prior research focuses specifically on studies that use new data sources to understand
24 the impacts of extreme weather on the transportation system in the New York City region.
25   One noteworthy study measured the resilience of the New York City transportation system
26 after Hurricane Sandy using data from taxi GPS traces (*7*). The findings suggest that Hurricane
27 Sandy impacted roadway traffic conditions for more than five days, and that significant traffic
28 delays were encountered during the post-disaster response period. A second noteworthy study used
29 two "big data" sources to assess the consequences of Hurricane Sandy and Hurricane Irene in New
30 York City (*8*). Post hurricane recovery patterns for the roadway and subway systems were analyzed
31 using taxi trip data and subway turnstile data, respectively. The method involved calculating the
32 rate of recovery, which was found to be lower for Hurricane Sandy compared to Hurricane Irene.
33 A third study developed a method to detect demand fluctuations and correlate them with disruptive
34 events (such as extreme weather conditions) using New York City taxi trip data *(9)*.
35   In summary, there are a number of emerging data sources that can help to quantify the
36 impacts of extreme events on transportation system performance. However, to the best of the
37 authors' knowledge, prior research has not considered the relationship between extreme events
38 and transportation app utilization. Therefore, the objective of this study is to explore the use of
39 transportation information provided via smartphone applications during an extreme weather event.
40 The specific dataset used in this analysis is from a smartphone application called "Transit," which
41 is available in numerous cities *(10, 11*, *12*). Because of the multi-city nature of the Transit app, the
42 dataset allows for a comparison between three cities that were affected by the snowstorm of
43 January 2016: New York City, Philadelphia, and Washington, D.C.
44
45
46

1 **BACKGROUND ON THE WINTER STORM**
2 Winter Storm Jonas paralyzed the eastern United States from Friday, January 22, 2016 to Sunday,
3 January 24, 2016. Between 20 and 30 inches of snow accumulated in New York City, Philadelphia
4 and Washington, D.C. (*13*). On Friday, January 22, government officials in Washington, D.C.
5 declared a snow emergency (*14*), and the local government in Philadelphia did the same. The
6 following day (January 23), officials in New York City declared a travel ban. In each of these three
7 cities, transit services were gradually shutdown, beginning before the storm in some areas and
8 resulting in a complete shutdown during the worst periods of the snowstorm. Additionally, Uber
9 service was officially shutdown in New York City (*15*).
10 The hour-by-hour status of public transit and shared mobility services (specifically, Uber)
11 before, during, and after the snowstorm are shown in Figure 1. This information was compiled
12 from transportation authority websites, local media sources, and social media.
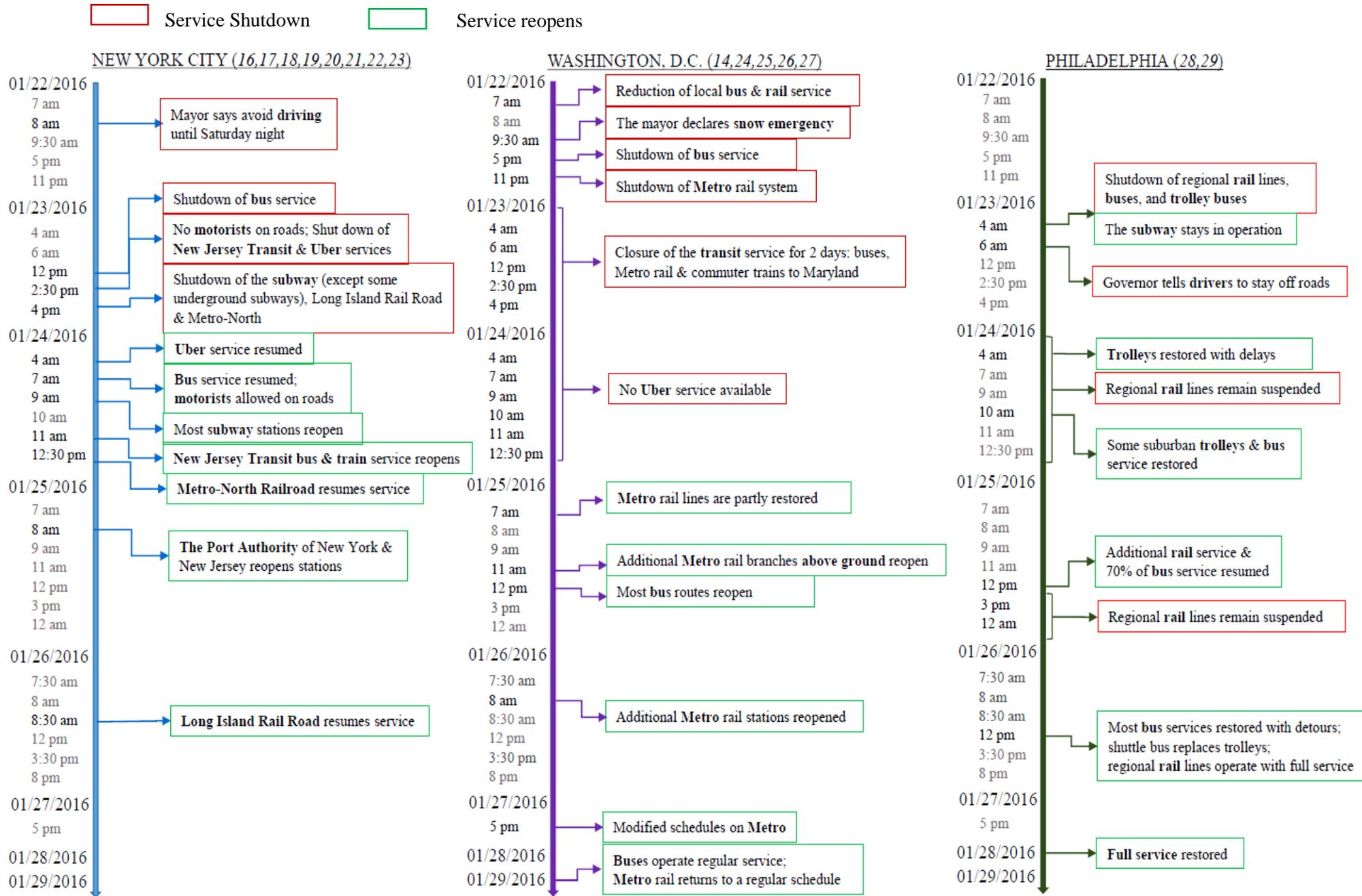
Remy, Brakewood, Ghahramani, Kwak & Peters

☐ Service Shutdown   ☐ Service reopens

NEW YORK CITY (16,17,18,19,20,21,22,23)

01/22/2016
- 7 am
- 8 am — Mayor says avoid **driving** until Saturday night
- 9:30 am
- 5 pm
- 11 pm

01/23/2016
- 4 am — Shutdown of **bus** service
- 6 am — No **motorists** on roads; Shut down of **New Jersey Transit & Uber** services
- 12 pm
- 2:30 pm — Shutdown of the subway (except some underground subways), Long Island Rail Road & Metro-North
- 4 pm

01/24/2016
- 4 am — **Uber** service resumed
- 7 am — **Bus** service resumed; **motorists** allowed on roads
- 9 am
- 10 am — Most **subway** stations reopen
- 11 am
- 12:30 pm — **New Jersey Transit bus & train** service reopens

01/25/2016 — Metro-North Railroad resumes service
- 7 am
- 8 am
- 9 am — The Port Authority of New York & New Jersey reopens stations
- 11 am
- 12 pm
- 3 pm
- 12 am

01/26/2016
- 7:30 am
- 8 am
- 8:30 am — **Long Island Rail Road** resumes service
- 12 pm
- 3:30 pm
- 8 pm

01/27/2016
- 5 pm

01/28/2016

01/29/2016

WASHINGTON, D.C. (14,24,25,26,27)

01/22/2016
- 7 am — Reduction of local **bus & rail** service
- 8 am — The mayor declares snow **emergency**
- 9:30 am — Shutdown of **bus** service
- 5 pm
- 11 pm — Shutdown of **Metro rail** system

01/23/2016
- 4 am
- 6 am — Closure of the **transit** service for 2 days: buses, Metro rail & commuter trains to Maryland
- 12 pm
- 2:30 pm
- 4 pm

01/24/2016
- 4 am
- 7 am
- 9 am — No **Uber** service available
- 10 am
- 11 am
- 12:30 pm

01/25/2016
- 7 am — Metro rail lines are partly restored
- 8 am
- 9 am
- 11 am — Additional **Metro rail** branches **above ground** reopen
- 12 pm — Most **bus** routes reopen
- 3 pm
- 12 am

01/26/2016
- 7:30 am
- 8 am
- 8:30 am — Additional **Metro rail** stations reopened
- 12 pm
- 3:30 pm
- 8 pm

01/27/2016
- 5 pm — Modified schedules on **Metro**

01/28/2016 — Buses operate regular service; **Metro rail** returns to a regular schedule

01/29/2016

PHILADELPHIA (28,29)

01/22/2016
- 7 am
- 8 am
- 9:30 am
- 5 pm
- 11 pm — Shutdown of regional **rail** lines, buses, and **trolley** buses

01/23/2016
- 4 am — The **subway** stays in operation
- 6 am
- 12 pm
- 2:30 pm — **Governor** tells **drivers** to stay off roads
- 4 pm

01/24/2016
- 4 am — **Trolleys** restored with delays
- 7 am — Regional **rail** lines remain suspended
- 9 am
- 10 am
- 11 am — Some suburban **trolleys & bus** service restored
- 12:30 pm

01/25/2016
- 7 am
- 8 am
- 9 am — Additional **rail** service & 70% of **bus** service resumed
- 11 am
- 12 pm
- 3 pm — Regional **rail** lines remain suspended
- 12 am

01/26/2016
- 7:30 am
- 8 am
- 8:30 am — Most **bus** services restored with detours; shuttle **bus** replaces **trolleys**; regional **rail** lines operate with full service
- 12 pm
- 3:30 pm
- 8 pm

01/27/2016
- 5 pm

01/28/2016 — **Full** service restored

01/29/2016

FIGURE 1 Timeline of the Snowstorm.

Remy, Brakewood, Ghahramani, Kwak & Peters

1 **DATASET**
2 This section contains a general description of the smartphone app data used in this analysis. The
3 first part gives a brief overview of the smartphone app, the second part defines the geographic area
4 of analysis, and the last section includes a brief description of the data files.
5
6 **Overview of the Smartphone Application**
7 The Transit app is a smartphone application available on Android and iPhone that provides
8 information about public transportation and shared mobility services, such as bikeshare, carshare,
9 and ridehailing (*10*). The Transit app covers New York City, Philadelphia, Washington, D.C. and
10 approximately 125 other cities. The app includes many features, such as real-time transit vehicle
11 information (see left screenshot in Figure 2), trip planning (see right screenshot in Figure 2), transit
12 service alerts, and multimodal support including Uber. When using the Uber feature, it should be
13 noted that the user can click "request an Uber" in the Transit app, but s/he will be directed to
14 Uber's app to complete the Uber order.
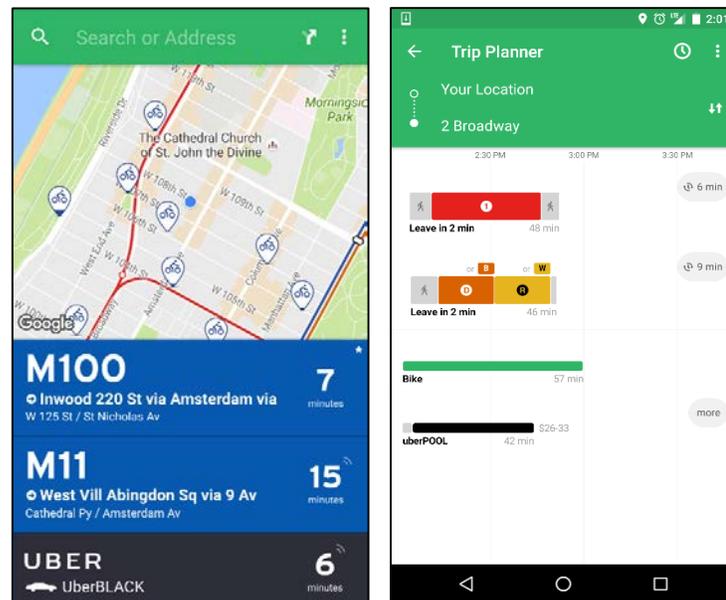
32 **FIGURE 2 Transit App Screenshots.**

34 **Time Period and Geographic Area of Analysis**
35 The time period for this study is Friday, January 8, 2016 to Friday, January 29, 2016; that is two
36 weeks before the snowstorm and one week after. The geographic areas are the regions of New
37 York City, Philadelphia, and Washington, D.C. The boundaries of the three regions were selected
38 based on the Metropolitan Planning Organization areas (*30, 31, 32, 33, 34*). Specifically, three
39 bounding boxes were drawn to define the maximum and minimum latitude and longitude for each
40 area. The New York area includes the region served by the New York Metropolitan Transportation
41 Council (NYMTC) (*30*) and the North Jersey Transportation Planning Authority (NJTPA) (*31*),
42 which is shown in Figure 3 in yellow. The Philadelphia area includes the regions served by the
43 Delaware Valley Regional Planning commission (DVRPC) (*33*) and the South Jersey
44 Transportation Planning Organization (SJTPO) (*34*), which is shown in green in Figure 3. Last,
45 the Washington, D.C. area was selected using the region served by the Capital Region
46 Transportation Planning Board (TPB) (*32*) shown in blue in Figure 3.
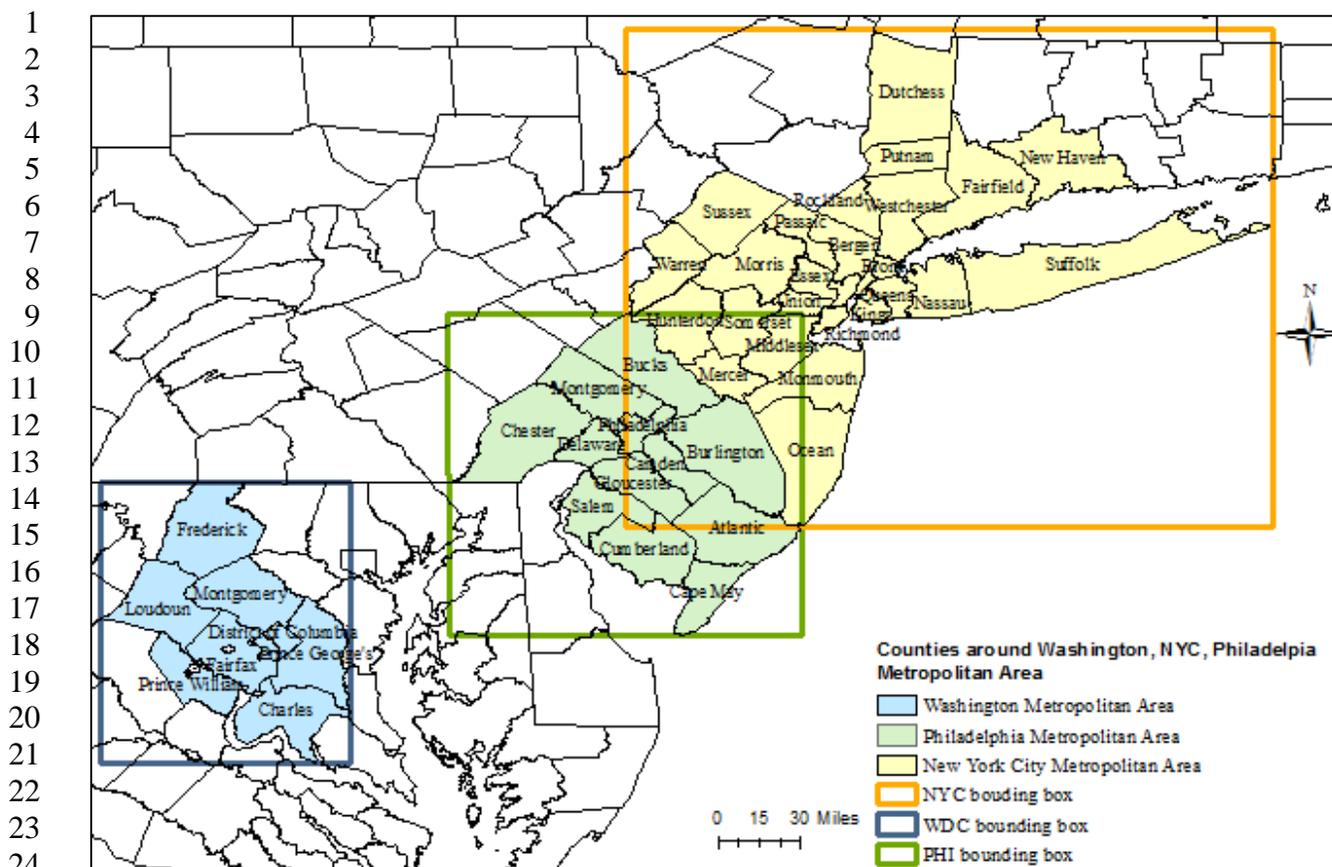
FIGURE 3 Bounding boxes around the New York City, Philadelphia, and Washington, D.C. Metropolitan Areas.

Data Description

The data used in this analysis was provided by the Transit app to the research team. The dataset contains user interactions with the app. Each time a user opens the apps, a unique session identifier (ID) is created, the time is recorded, and the location of the user (latitude/longitude) is stored. Between January 8 and January 29, 2016, there were millions of Transit app sessions in the areas of analysis.

The following analysis also uses a subset of the data that includes all Uber requests made through the Transit app. Each time users click to request an Uber in the Transit app, the user's location (latitude/longitude) and the time of the request are recorded. Between January 8 and January 29, 2016, there were thousands of Uber requests in the areas of analysis.

ANALYSIS

An analysis of Transit app utilization during the January 2016 snowstorm was conducted in four parts. First, overall Transit app usage patterns were visually explored, and then the rate of use was calculated by comparing app use during the snowstorm to a regular period. Next, a regression model of total hourly app use was created. Last, the use of the Uber feature in the Transit app was investigated in a visual analysis. The results of this analysis are described in the following sections.

Remy, Brakewood, Ghahramani, Kwak & Peters

Part 1: Visualization of Transit App Usage

First, overall Transit app usage patterns were visually explored. During the three-week period of analysis, the total Transit app usage per hour in each region was calculated. This was then compared to the mean app usage per hour during the two first weeks before the snowstorm when there were normal weather conditions (January 8 to January 15).

Figure 4 shows hourly Transit app usage (the black line) compared to the mean hourly usage (the red line) for each of the three regions. Utilization of the app has a strong periodic weekly pattern. There is a peak during the morning rush hour and another during the evening rush hour for weekdays, and app usage decreases during the weekend. However, this typical pattern was interrupted during the snowstorm period, as can be seen in Figure 4. The vertical line in yellow shows the period when the snowstorm hit each of the three cities, and the vertical line in blue displays when the transit systems were closed. During this period, the amount of overall app usage per hour in each city was less than the mean. In the New York City area and in the Philadelphia area, this decrease is more pronounced on Saturday January 23 during the afternoon. For the Washington, D.C. area, the decrease in app usage began earlier (on Friday January 22) and stayed below the mean for longer than the two other areas.

Part 2: Rate of Transit App Use

Next, the rate of Transit app use was calculated in a similar manner to a previous paper on extreme events *(8)* by comparing mean hourly usage prior to the snowstorm with hourly app usage during the snowstorm for each city. For every hour *t*, the rate of use $R(t)$ was calculated by dividing the hourly app usage, $U(t)$, by the mean hourly usage, $Q(t)$, during the reference period, which was the two weeks before the snowstorm. Equation [1] shows the rate of use formula:

$$R(t) = \frac{U(t)}{Q(t)} \qquad\qquad [1]$$

Figure 5 displays the results of the rate of use calculation for each of the three cities as a black line. The red line in Figure 5 shows 100%, which is the typical usage during the reference period. As can be seen in Figure 5, the three cities generally exhibit similar patterns. The rate of use is fairly consistent during the two weeks prior to the storm, and all three cities have a dip in use on the Martin Luther King, Jr. holiday, which was Monday, January 18, 2016. During the snowstorm, all three cities initially exhibited an increase in the rate of use, but this quickly decreased below the 100% level as the snowstorm continued.

In New York City, the rate of app usage dropped below 100% on Saturday, January 23 before noon and remained low until the following day (Sunday, January 24). On Saturday, most transit service in New York City was shut down during the snowstorm (with the exception of some underground areas of the subway), and it was during this time that the rate of use reached its lowest point (approximately 65% of mean usage). After the snowstorm finished and transit service was largely restored on Monday, January 25, a peak appeared during the morning rush hour, and the rate of use reached about 165%. This may be because Transit app users wanted more information as they went back to work to assure them that transit service was fully restored.

In the Philadelphia area, the rate of Transit app use initially increased on Friday, January 22 around 12pm; at this time, a snow emergency had been declared *(37)* but the transit system had not yet shutdown. This spike in use is likely because Transit app users were searching for information to get home before the snowstorm. Shortly thereafter, during the nighttime on Friday,

Remy, Brakewood, Ghahramani, Kwak & Peters

1   January 22, the rate of use dropped substantially below 100% and stayed low until the morning of
2   January 24, 2016. On Saturday 23, when Philadelphia transit authorities suspended all their
3   services (Figure 1), the rate of use reached about 65% of the mean usage, which was the lowest
4   point. After the snowstorm finished and transit service was largely restored on Monday, January
5   25, a small increase in the rate of use appeared during the morning rush hour.
6   In the Washington, D.C. area, the rate of Transit app use dropped below 100% for most
7   hours from January 22 at noon until January 25 at midnight. After the storm, the rate of use took
8   longer to stabilize compared to the other metropolitan areas, which may have been because the
9   recovery time of the transit systems in this region was longer than the other areas (Figure 1). For
10 example, it was not until Tuesday, January 26 that most of the Washington, D.C. metro system
11 was reopened (with 86 of 91 Metrorail stations opened by Tuesday January 26). Consequently,
12 app users in Washington, D.C. seemed to be more affected by the snowstorm than those in New
13 York City or Philadelphia.
14   Finally, it should be noted that some peaks in Figure 5 are not meaningful due to data
15 limitations. For example, a peak in the rate of use appeared in each of the three cities on Monday,
16 January 11. This is because the other Monday used to calculate the mean (reference) hourly usage
17 was Martin Luther King Day. Future analyses should expand the period of analysis to
18 accommodate this.

Remy, Brakewood, Ghahramani, Kwak & Peters
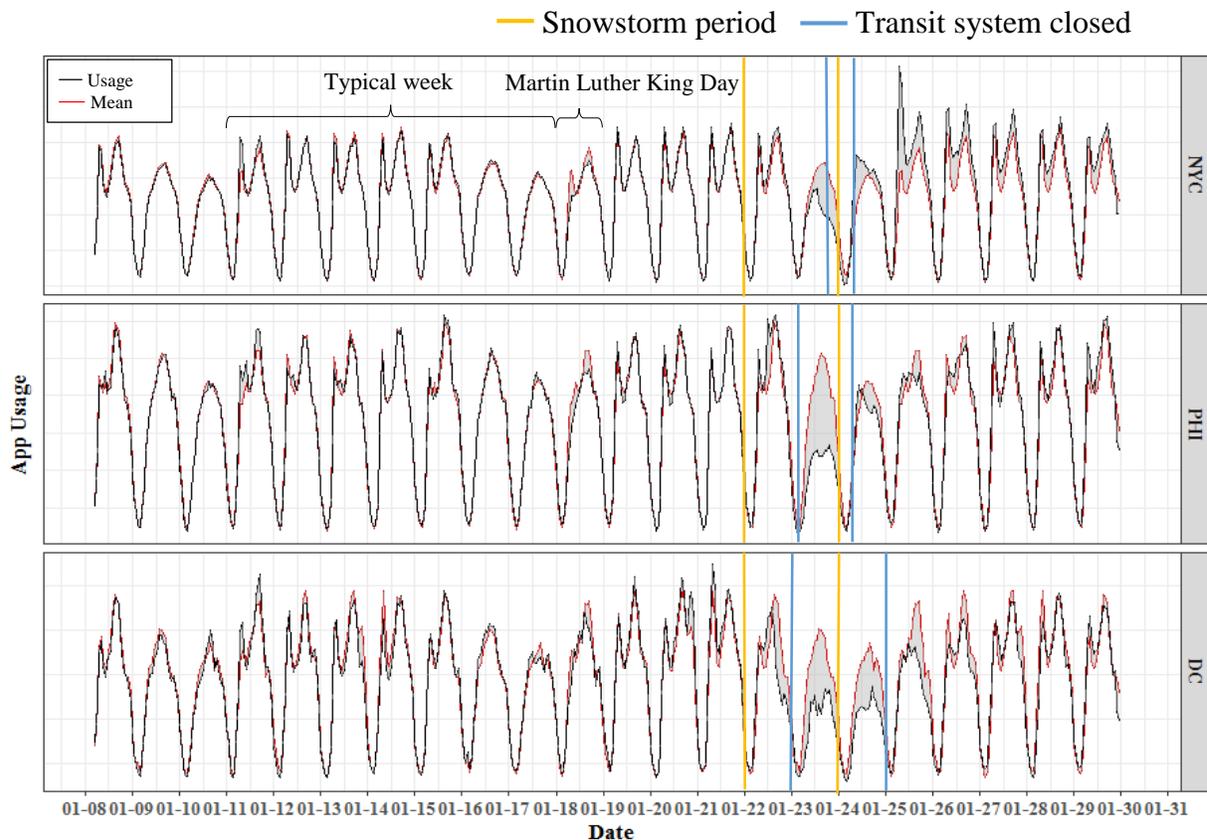
FIGURE 4 App usage and mean usage in New York City, Philadelphia and Washington, D.C.
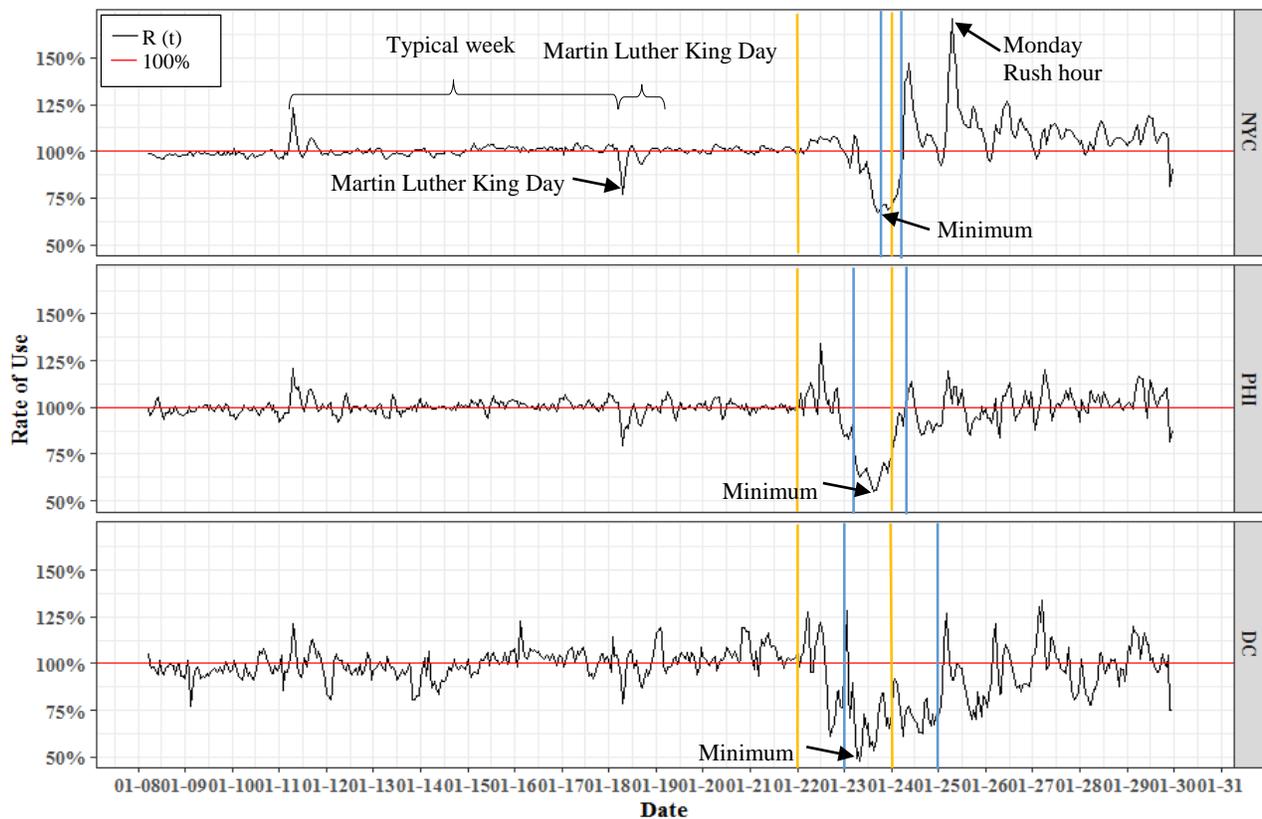
FIGURE 5 Rate of app use in New York City, Philadelphia and Washington, D.C.

Remy, Brakewood, Ghahramani, Kwak & Peters

1 **Part 3: Regression Model of Transit App Use**
2 Next, three Ordinary Least Squares (OLS) regression models were estimated: one for New York
3 City, one for Philadelphia and one for Washington, D.C. In each regression model, the dependent
4 variable is the number of Transit app records per hour in the corresponding city. For independent
5 variables, eight binary variables were defined to account for the effects of Martin Luther King Day
6 (on Monday January, 18), three days of the snowstorm (Friday January, 22 to Sunday, January
7 24), and four days after the snowstorm (from Monday January, 25 to Thursday, January 28). Also,
8 to control for the typical weekly app usage pattern, 167 binary variables were included in each
9 model to account for the 168 hours in a week. Equation [2] below shows the regression model
10 formulation, which is the same for each city (New York City, Philadelphia and Washington, D.C.):

$$Y_t = \alpha + \sum_{i=1}^{167} \beta_i h_i + \beta_{168}MLKD + \beta_{169}SD1 + \beta_{170}SD2 + \beta_{171}SD3$$

$$+\beta_{172}RD1 + \beta_{173}RD2 + \beta_{175}RD3 + \beta_{176}RD4 \qquad [2]$$

11 Where:
12 • Y_t = Number of Transit app records per hour *t*
13 • h_1 to h_{167} = Binary variables representing each hour of the week (i.e., h_1 represents Friday at
14   12am, h_{25} represents Saturday at 12am, and h_{167} represents Thursday at 11 pm)
15 • MLKD = Binary variable representing Martin Luther King Day
16 • SD1 to SD3 = Binary variables representing the first, second, and third day of the snowstorm
17   from Friday, January, 22 to Sunday, January, 24, respectively
18 • RD1 to RD4 = Binary variables representing the first to fourth days after the snowstorm from
19   Monday, January 25 to Thursday, January, 28
20
21 The results of the regression models for each city are presented in Table 1. All three models have
22 high R-squared values, and more than 90% of variation in the data can be explained by the model
23 for each city. The F-statistic is significant for each model, which confirms the high joint
24 significance of the variables.
25   For the New York City regression model, all eight binary variables representing Martin
26 Luther King Day, the snowstorm days, and recovery days are significant (p-value < 0.01); this
27 means that holidays and extreme weather strongly affect Transit app utilization. The coefficient
28 for Martin Luther King Day is negative (-3,843.750), suggesting that app usage decreases on
29 holidays. On Friday, January 22, when the snowstorm first hit New York City, the number of
30 Transit app records increased (coefficient of 2,773.521); this increase may be due to a perceived
31 disruption in the transit system. However, on the second day of the storm when the transit system
32 was shut down and a travel ban for motorists was imposed, Transit app usage decreased
33 significantly (coefficient of -8,925.938). On the last day of the snowstorm, when motorists were
34 allowed on the roads and the transit system began to reopen, the number of Transit app records
35 increased (coefficient of 4,110.063). The greatest change in Transit app usage was observed on the
36 first day after the snowstorm on Monday, January 25, which had a large positive coefficient
37 (9,709.958). On this day, users were likely searching for transit information for their commute
38 trip. On the subsequent days after the snowstorm, Transit app usage was larger than usage on

Remy, Brakewood, Ghahramani, Kwak & Peters

1   normal days, which is indicated by the positive significant coefficients on the second, third, and
2   fourth recovery days (7,013.187, 4,903.354, and 3,544.271, respectively).
3   In Philadelphia, the binary variables representing Martin Luther King Day, the three days
4   of the snowstorm, and the first day after the snowstorm were strongly significant (p-value < 0.01).
5   The effect on Martin Luther King Day is similar to that observed in New York City; Transit app
6   usage was less than normal days (coefficient of -576.625) on the holiday. On the first and second
7   days of the snowstorm, app usage was higher than usual (coefficient of 381.437 and 2,200.625,
8   respectively). On the last day of the snowstorm (Sunday, January 24), the number of Transit app
9   records decreased, which is expected due to the transit system shut down over the weekend
10   (coefficient of -389.958). The decrease in Transit app usage continued on the first day after the
11   snowstorm (coefficient of -373.292) even though the transit system resumed service and it was a
12   weekday (Monday, January 25). Two days after the snowstorm, the number of Transit app records
13   increased, and this increase continued during the third day and fourth days of recovery after the
14   storm.
15   In Washington, D.C., the coefficients are significant (p-value < 0.05) for the binary
16   variables representing Martin Luther King Day, the three days of the snowstorm, and one day after
17   the snowstorm. All of the coefficients for the storm days and the recovery days in this model are
18   negative, which means that Transit app records decreased during the storm and continued to be
19   lower than normal after the snowstorm. The transit system in Washington, D.C. resumed service
20   on the first day after the snowstorm (Monday, January 25) but took longer to get back to normal.
21   This model suggests that Washington, D.C. had the slowest recovery in Transit app usage of the
22   three cities.

1 **TABLE 1 Regression Results for New York City, Philadelphia & Washington, D.C.**

	NYC	PHI	DC
Intercept	79,173.600***	8,568.542***	10,523.240***
	(2455.90)	(271.23)	(496.43)
Mon. Jan. 18 (Martin Luther King Day)	-3,843.750***	-576.625***	-547.333**
	(1,215.36)	(134.23)	(245.67)
Fri. Jan. 22 (1st day of snowstorm)	2,773.521***	381.437***	-528.813**
	(1052.53)	(116.24)	(212.75)
Sat. Jan. 23 (2nd day of snowstorm)	-8,925.937***	2,200.625***	-2,202.167***
	(1052.53)	(116.24)	(212.75)
Sun. Jan 24 (3rd day of snowstorm)	4,110.062***	-389.958***	-1,802.104***
	(1052.53)	(116.24)	(212.75)
Mon. Jan. 25 (1st day after snowstorm)	9,709.958***	-373.292***	-1,377.792***
	(1215.36)	(134.23)	(245.67)
Tues. Jan. 26 (2nd day after snowstorm)	7,013.187***	43.375	-525.708**
	(1052.53)	(116.24)	(212.75)
Wed. Jan. 27 (3rd day after snowstorm)	4,903.354***	250.750**	-48.19
	(1052.53)	(116.24)	(212.75)
Thurs. Jan. 28 (4th day after snowstorm)	3,544.271***	173.25	-411.500*
	(1052.53)	(116.24)	(212.75)
Observations	504	504	504
R^2	0.97	0.977	0.949
Adjusted R^2	0.955	0.965	0.922
Residual Std. Error (df = 328)	4,210.11	464.97	851.014
F Statistic (df = 175; 328)	61.650***	79.951***	35.105***

Notes: *p<0.1; **p<0.05; ***p<0.01
Standard error shown in parenthesis.
167 hourly dummy variables not presented in the table; available upon request.

2 **Part 4: Visualization of Uber Requests**
3 Besides overall Transit app usage, Uber requests made through the app were also considered. The
4 dataset contains all sessions in which a user opened the app and clicked on "Request an Uber."
5 However, users cannot book an Uber directly within the Transit app; instead, they are directed to
6 Uber's app for fulfillment. Consequently, the Transit app dataset only highlights the users'
7 intention of taking Uber and does not reflect actual Uber trips.
8   Figure 6 shows daily Uber requests through the Transit app and a comparison with the
9 mean of the previous two weeks. The amount of data was very small compared to overall Transit
10 app use; thus, the analysis was conducted on a daily basis instead of hourly. As can be seen in
11 Figure 6, the yellow line shows when the snowstorm hit the three cities, the line in blue is when
12 the transit systems were closed, and the line in green represents the travel ban or snow emergency
13 period. It should be noted that in New York City, Uber service was officially suspended from
14 Saturday, January 23 at 2:30 pm until Sunday, January 24 at 4 am (Figure 1). In Philadelphia and
15 in Washington, D.C., a reference stating that Uber service was suspended could not be found;

Remy, Brakewood, Ghahramani, Kwak & Peters

1   however, the authorities asked citizens to stay off of the roads in both cities (*34*, *35*), so it assumed
2   that Uber was not operating during this time.

3   In New York City, the total number of Uber requests via the Transit app was between 300
4   and 600 per day during the reference period prior to the storm. Interestingly, the number of Uber
5   requests was higher during the snowstorm period. On Sunday, January 24, the number of Uber
6   requests reached a peak of 1,750 in New York City. In Philadelphia, the number is between 50 and
7   150 per day prior to the storm and reached 280 requests during the storm. For Washington, D.C.,
8   the number of Uber requests was between 75 and 180 per day prior to the storm, and the highest
9   peak represented more than 300 requests on Monday, January 25. Unlike the two others cities, the
10   lowest point in Washington, D.C. occurred on Saturday, January 23 when no vehicles were
11   allowed on roads and the transit system was shut down.

12   The results imply that despite travel bans, the number of Uber requests was greater than
13   usual. During the snowstorm, Transit app users were probably looking for other modes of travel
14   when the transit systems were shut down. When the transit systems began to reopen service (on
15   Sunday in New York City and in Philadelphia and on Monday in Washington, D.C.), the number
16   of Uber requests via the Transit app reached the highest point. Last, it is important to emphasize
17   that these are requests for Uber, which do not necessarily involve fulfilled trips; Transit app users
18   are directed to Uber's app for fulfillment.
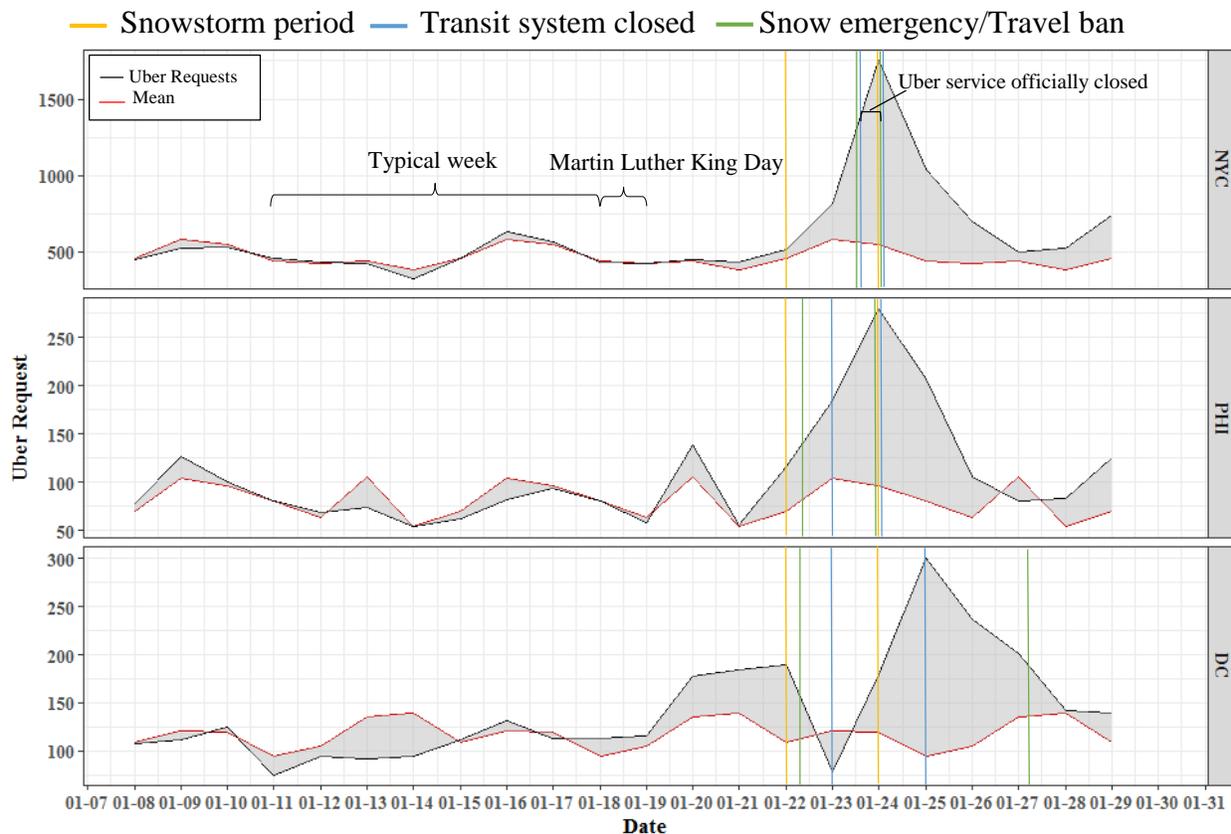
FIGURE 6 Daily Uber Requests and Mean Uber Requests in New York City, Philadelphia, and Washington, D.C.

1 **CONCLUSIONS AND FUTURE RESEARCH**
2 This study assessed information utilization during an extreme weather event by analyzing data
3 from a smartphone app called Transit, which provides real-time transit and shared mobility
4 information in many North American cities. The analysis focused on a snowstorm that hit the
5 northeastern USA in January 2016 and severely disrupted transit and shared mobility services. A
6 four-part analysis was conducted for three cities: New York City, Philadelphia, and Washington,
7 D.C. First, hourly Transit app utilization during the snowstorm was compared to the mean hourly
8 app utilization prior to the storm. Second, the rate of app usage was calculated by dividing hourly
9 utilization during the storm by the mean hourly volume before the storm. Third, an ordinary least
10 squares regression model of hourly app usage was estimated for each city. Last, a feature within
11 the app used to request Uber vehicles was examined.
12   The results of the first three analyses revealed that overall app usage decreased during the
13 snowstorm in all three cities. After the storm, New York City experienced a significant increase in
14 overall app use during the first Monday commuting period, and Washington, D.C. had the slowest
15 recovery in app usage. The analysis of Uber data revealed that Transit app users continued to
16 search for ridehailing services during the snowstorm, despite travel bans. Although some of the
17 findings of this study are to be expected – such as the decrease in overall Transit app usage during
18 the storm and an increase immediately afterward – the number of Transit app searches during the
19 snowstorm was surprisingly large, particularly during the period when the transit systems were
20 completely shut down (i.e., a decrease to only about 65% of mean use).

Remy, Brakewood, Ghahramani, Kwak & Peters

1   These findings are important for transportation operators and app developers to understand
2 how travelers use information from smartphone apps during extreme weather events, which would
3 be very difficult to do using traditional data sources such as surveys. This new type of technology
4 – smartphone apps – largely did not exist a decade ago and has rapidly changed how transit
5 agencies communicate with travelers. However, traveler utilization of this new technology –
6 particularly during unusual or extreme events – has not been well documented. If usage patterns
7 are better understood, it can help transit agencies to better communicate with travelers during
8 extreme events and potentially help transit systems to recover faster by improving communication
9 channels. This analysis shows that travelers want to be informed of changes in transportation
10 service, as evidenced by large spikes in Transit app usage after the snowstorm, and therefore,
11 transportation providers should anticipate increased communication levels immediately after
12 extreme weather events. Transportation operators should also consider multiple means of
13 communication (beyond just apps) to ensure that they reach all of the traveling public.
14   Last, many interesting areas for future research emerged from this analysis. First, the
15 analysis of Winter Storm Jonas could be expanded to other regions, including areas that were not
16 as heavily impacted by the snow as New York City, Philadelphia, and Washington, D.C. Another
17 interesting area for future research is to examine Transit app usage patterns at the individual level,
18 instead of at the metropolitan level. Additionally, the continuous nature of this dataset enables
19 other anomalous events to be studied, including both planned events such as concerts or sports
20 events and unplanned events such as hurricanes. Finally, it would be interesting to compare
21 utilization of the Transit app to use of other transportation-related smartphone applications;
22 however, in order for comparative analyses to be possible, the developers of other applications
23 (which are often private companies) must be willing to share usage data. Hopefully there will be
24 increased willingness to share data in the future as utilization of smartphone apps continues to
25 grow.
26
27 **ACKNOWLEDGEMENTS**

Remy, Brakewood, Ghahramani, Kwak & Peters

REFERENCES
1. The Weather Channel. *Winter Storm Jonas: Where Does It Rank Historically?* January 24, 2016. https://weather.com/storms/winter/news/winter-storm-jonas-rank-in-history. Accessed August 1, 2017.
2. Chang and Nojima. Measuring Post-disaster Transportation System Performance: the 1995 Kobe Earthquake in Comparative Perspective. *Transportation Research Part A: Policy and Practice.* Vol. 35, 2011, pp.475-494.
3. Knapp, Smithson, and Khattak. The Mobility and Safety Impacts of Winter Storm Events in a Freeway Environment. *Mid-continent Transportation Symposium Proceedings*, 2000, pp. 67-71.
4. He and Liu. Modeling the Day-to-day Traffic Evolution Process after an Unexpected Network Disruption. *Transportation Research Part B,* Vol. 46, 2012, pp. 50–71.
5. Cottrill, Gault, Yeboah, Nelson, Anable, and Budd. Tweeting Transit: An Examination of Social Media Strategies for Transport Information Management During a Large Event. *Transportation Research Part C: Emerging Technologies*, Vol. 77, 2017, pp. 421-432.
6. Pereira, Rodrigues, and Ben-Akiva. Using Data from the Web to Predict Public Transport Arrivals under Special Events Scenarios. *Journal of Intelligent Transportation Systems.* Vol. 19, No. 3, 2015, pp. 273-288.
7. Donovan and Work. Empirically Quantifying City-scale Transportation System Resilience to Extreme Events. *Transportation Research Part C,* Vol. 79, 2017, pp.333–346.
8. Zhu, Ozbay, Xie, and Yang. Using Big Data to Study Resilience of Taxi and Subway Trips for Hurricanes Sandy and Irene. *Transportation Research Record: Journal of the Transportation Research Board,* No. 2599, 2016, pp. 70–80.
9. Markou, Rodrigues, and Pereira. Demand Pattern Analysis of Taxi Trip Data for Anomalies Detection and Explanation. Proceedings of the *96th Annual Meeting of the Transportation Research Board*, 2017.
10. Ghahramani and Brakewood. Trends in Mobile Transit Information Utilization: An Exploratory Analysis of Transit App in New York City. *Journal of Public Transportation*, Vol. 19, No. 3, 2016, pp. 139-160.
11. Davidson, Peters and Brakewood. Interactive Travel Modes: Uber, Transit and Mobility in New York City. Proceedings of the *96th Annual Meeting of the Transportation Research Board*, 2017.
12. Ghahramani, Brakewood and Peters. An Exploratory Analysis of Intercity Travel Patterns using Backend Data from a Transit Smartphone Application, *96th Annual Meeting of the Transportation Research Board*, 2017.
13. National Oceanic and Atmospheric Administration. *The Historic Nor'easter of January 2016*. https://www.weather.gov/media/publications/assessments/16Northeast_Blizzard.pdf, Accessed July 29, 2017.
14. Office of the Mayor, *Executive Office of the Mayor*. January 21, 2016. https://mayor.dc.gov/release/mayor-bowser-declares-public-emergency-district-columbia-ahead-winter-storm. Accessed July 25, 2017.
15. Forbes. *Winter Storm Jonas Knocks Out Uber In New York, New Jersey*. January 23, 2016. https://www.forbes.com/sites/briansolomon/2016/01/23/winter-storm-jonas-knocks-out-uber-in-new-york-new-jersey/#12b164934cb2. Accessed July 25, 2017.
16. New York State, January 24, 2016. https://www.governor.ny.gov/news/governor-cuomo-issues-update-mta-service-suspensions. Accessed July 24, 2017.

Remy, Brakewood, Ghahramani, Kwak & Peters

17. New York City Metropolitan Transportation Authority. *MTA Archive Alert*. https://www.mymtaalerts.com/messagearchive.aspx. Accessed July 24, 2017.
18. New York City Metropolitan Transportation Authority. *MTA Service Advisory.* http://web.archive.org/web/20160123182337/http:/alert.mta.info/. Accessed July 24, 2017
19. New York City Metropolitan Transportation Authority. *MTA info*, January 24, 2016 http://www.mta.info/news-blizzard/2016/01/24/approximately-80-lirr-customers-can-use-rail-service-tomorrow. Accessed July 24, 2017.
20. CBS New York. *PATH Service Restored Between Newark And Journal Square.* January 26, 2016. http://newyork.cbslocal.com/2016/01/26/path-service-restored-newark-journal-square/. Accessed July 24, 2017.
21. NJ.com. *NJ Transit to Resume Service Sunday Following Blizzard.* January 24, 2016. http://www.nj.com/news/index.ssf/2016/01/nj_transit_back_up_and_running_after_blizzard.html. Accessed July 31, 2017.
22. Twitter, Uber NYC Account, January 24 2016. https://twitter.com/Uber_NYC/status/691235011488522240. Accessed July 24, 2017.
23. NYC Housing Preservation & Development. *Public Service Announcement*, January 22, 2016 http://www1.nyc.gov/site/hpd/about/public-service-announcements/1-22-16.page. Accessed July 25, 2017.
24. Washington Metropolitan Area Transit Authority. *Daily Service Report Archives*. https://www.wmata.com/service/daily-report/archives.cfm?year=2016. Accessed July 24, 2017.
25. Maryland Department of Transportation. Maryland Transit Administration. https://mta.maryland.gov/mta-temporarily-suspend-weekend-transit-services. Accessed July 24, 2017.
26. CBS Maryland. *Limited Service Continues For MTA Maryland.* January 26th 2016. http://baltimore.cbslocal.com/2016/01/26/limited-service-continues-for-mta-maryland/. Accessed July 24, 2017.
27. CBS Maryland. *MTA Offering Free Rides Monday Due To Snow*. January 26th 2016. http://baltimore.cbslocal.com/2016/01/24/mta-offering-free-rides-monday-due-to-snow/. Accessed July 24, 2017.
28. Southeastern Pennsylvania Transportation Authority. *Press Releases*. http://www.septa.org/media/releases/. Accessed July 24, 2017.
29. Philly.com. *Winter Storm Recovery Updates: Jan. 28, 2016.* http://www.philly.com/philly/blogs/real-time/Winter-storm-recovery-updates-Jan-25-2016.html. Accessed July 24, 2017.
30. New York Metropolitan Transportation Council. https://www.nymtc.org/. Accessed July 24, 2017.
31. New Jersey Transportation Planning Authority. http://njtpa.org/home. Accessed July 24, 2017.
32. Metropolitan Washington Council of Governments. https://www.mwcog.org/tpb/. Accessed July 24, 2017.
33. Delaware Valley Regional Planning Commission. http://www.dvrpc.org/. Accessed July 24, 2017.
34. South Jersey Transportation Planning Authorization. http://sjtpo.org/. Accessed July 24, 2016

Remy, Brakewood, Ghahramani, Kwak & Peters

35. Office of the Mayor, *Executive Office of the Mayor*. January 21, 2016. https://mayor.dc.gov/release/mayor-bowser-declares-public-emergency-district-columbia-ahead-winter-storm. Accessed July 25, 2017.
36. Governor of Pennsylvania, *Press Releases*. January 23, 2016. https://www.governor.pa.gov/governor-wolf-gives-winter-storm-update-strongly-urges-public-not-to-travel/. Accessed July 25, 2017.
37. CBS Philadelphia. *Snow Emergency Begins in Philadelphia 9pm Friday.* January 22, 2016. http://philadelphia.cbslocal.com/2016/01/22/snow-emergency-begins-in-philadelphia-9-pm-friday/. Accessed August 1, 2017.