Congested Days in Toronto

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McMASTER INSTITUTE FOR TRANSPORTATION & LOGISTICS

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Executive Summary

While traffic congestion is a regular dinner-table conversation, media topic, and features centrally into discussions of transportation policy formation, newer data sources are only beginning to be integrated into policymaking circles as means to explore, track, and shape transportation system performance. This report represents one element of a larger study on using "Big Data" – in this case from Inrix, Inc. – to study road transportation system performance in the City of Toronto, focusing on the metric of travel speed. This study integrates data and model results from several sources to identify the slowest and fastest single days in 2014 (January 1 through December 31) and portions of 2011 (August 8 through December 31) and 2013 (July 1 through December 31). Only the freeways are analyzed for 2011 and 2013 while the freeway and arterial networks are each assessed independently for 2014 to focus the analysis on those system components which are best tracked by the available data for each year[1].

Results suggest four major findings when focusing on mean daily travel speeds of "typical days." First, weekend speeds are higher than weekday speeds. Freeway speeds are on average 7 to 10 kilometers per hour faster during weekdays than during the week. Second, most of the very slowest days of the year can be explicitly matched to snow and rain events. Third, those weekdays with atypically fast mean travel speeds are on holidays. Finally, daily travel conditions are much less stable during winter months than during summer months. This appears to be due to the joint impacts of the previous two factors: holidays (on which speeds are higher) and extreme weather events (during which speeds are lower). In sum, although severe incidents which trigger broader gridlock may severely impact the experiences of many downstream system users, the most pronounced patterns in daily freeway travel conditions stem from factors which are largely outside of the purview of policymaking: holidays, weekends, and weather.

[1] Both arterial and freeway data are available for each of the study years, but day-specific arterial performance is only assessed in 2014 due to the improvements in arterial network coverage between 2011 and 2014. Freeway coverage is much higher in each of the study years, enabling better day-specific assessments.

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Introduction

Most traffic congestion studies explore the intensity, extent, and implications of congestion in major regions using average annual levels for broad periods (Schrank, Eisele, & Lomax, 2012). This study focuses not just on averages across the year and instead explores day-to-day variations in road transportation system performance within the City of Toronto in 2014 and parts of 2011 (August 8 – December 31) and 2013 (July 1 – December 31). This analysis is both empirical and exploratory in nature. Empirical estimates of link-based travel services are used to identify daily variations of congestion within the study year. The results of this study explore whether unique days can be identified as particularly slow or fast, and if so, whether informing the public of these days might help better manage road transportation system performance in the future.

Data in this study are collected from Inrix, Inc. and represent a shift in using the analysis of “Big Data” to glean transportation system performance measures. Conventional congestion studies rely either on 1) estimated relationships between traffic volumes, capacities, and travel speeds on observed system assets (Schrank, Eisele, & Lomax, 2012)or 2) on conventional four-step travel demand models (Transport Canada, 2006) – which make similar assumptions about the relationships between volumes, capacities, and speeds. New data are becoming available which can be used to estimate travel speeds directly in lieu of being limited to estimating unknown speeds using what is known about volumes and capacities. This shift in data availability could represent a significant change in how transportation system performance could be conducted in a dynamic manner while estimating how moderate or large-scale changes in transportation services impact user experiences.

Why may it be useful to understand the day-to-day variations in congestion? Conventional transportation performance monitoring is about identifying “typical” trends which influence many users conducting trips comprising of both typical and atypical travel patterns. In contrast to this approach of focusing on the “typical” trends, this study focuses on the unique characteristics of different days when generalized to either the freeway system or the arterial system falling within the City of Toronto boundaries. Patterns demonstrate that both regular and irregular variations in transportation system performance can be observed from day to day. Each user’s route may be different and the characteristics of each trip may be unique, but this study identifies the extent to which City of Toronto road users share common challenges on specific days within the calendar year 2014 and much of 2011 and 2013. These time periods are selected to look at changes over time in the broader study of which this is part and due to limitations of data availability (the day-specific archived data from Inrix, Inc. has only been saved since August 8, 2011).

The task of analyzing road transportation system performance on specific days relies on assumptions about volumes, system extent, and the metric of choice. As such, this study introduces several key data elements which contribute to the analysis and shape the nature of study findings. This study uses volume estimates from the study team’s four-step travel demand model to weight the relative contributions of different links’ performance levels to aggregate up to a system-wide typical performance level. While these volumes do not account for net daily variations in congestion, in this study they are used to weight the relative contributions of different links towards congestion levels.

The findings from this study are limited to the calendar year of 2014 and portions of 2011 (August through December) and 2013 (July through December). As such, the daily variations in road system performance identified in this study represent a combination of trends which extend across multiple years and the unique characteristics of years in question.

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Study Design

This study employs Inrix, Inc. speed data to assess transportation system performance. Data from Inrix, Inc. is scaled up to estimate typical transportation system performance levels for different days, different years, and (in the case of 2014) differences between freeway system performance and arterial performance. As this study focuses on specific days in 2011, 2013, and 2014 as the units of observation, the largest methodological challenges are two-fold. The first challenge in employing Inrix, Inc. data to explore day-specific system performance lies in reasonably assessing daily differences by scaling up an admittedly unrepresentative sample (Inrix, Inc. probes are disproportionately represented by freight and vehicle fleets). The second challenge lies in comparing the congestion intensity of different types of days in an effort to identify what deviates from “normal”.

2.1 Necessary Inputs

Estimating transportation service levels at the level of granularity of specific days at specific times depends on exploring system performance using a number of high-quality data inputs and study decisions. In the case of this study, three fundamental inputs are needed:

1. traffic volume estimates,
2. speed data, and
3. roadway lengths.

Although road speed data which is attributable to particular road segments with known geometries might appear to be sufficient to extract road system performance metrics, traffic volume estimates are necessary to overcome potential issues in representativeness in the sample speed data.

2.1.1 Traffic Volume Estimates

Traffic volumes are estimated using the study team's custom four-step travel demand model, TRAFFIC. The software employs a conventional approach to estimating trip generation, distributing trips within the study area, allocating mode shares to trip pairs, and assigning routes based on conventional best-practices in the four-step modeling process and equilibration. Trips are generated using the 2006 Transportation Tomorrow Survey and updated estimates for more recent years are estimated using adjustments in trip generation and distribution based on expected growth locations within the region using external population and job forecasts and allocating these to the traffic zone level. Hemson Consulting (2012) projects job and population growth at the census division level and these forecasts are re-allocated to the smaller traffic zones (McMaster Institute for Transportation, 2014, pp. 32-36).

Using the hourly results from the four-step traffic model (which is estimated exclusively for a "typical" weekday), hour-specific traffic volumes are estimated for each link within the study area. As both the road network in TRAFFIC and other data used in this study are based on the DMTI network, volume estimates can be reasonably matched with other performance inputs and speed data. While these volumes do not account for net daily variations in congestion, in this study they are used to weight the relative contributions of different links towards congestion levels.

2.1.2 Speed Data

To estimate link-level and system-wide transportation service levels, road speed data are purchased from Inrix, Inc., a third-party provider of travel service information. Data are provided using Traffic Message Channel (TMC) links as the unit of observation. There are 1,911 TMCs included in the full City of Toronto network. Based on conversations between the study team and personnel from Inrix, Inc., traffic data is collected by vehicles through numerous sources, and many are parts of vehicle fleets which disproportionately include heavy vehicle operators.

While the variations in transportation system performance reflect both spatial and temporal variations in performance among the sampled users, the sample reflects the acceleration and deceleration patterns of the vehicles comprising the Inrix, Inc. vehicle probe fleet,. Based on the differences between vehicles comprising the Inrix, Inc. probe dataset and general road users, one would expect the potential issues of lack of representativeness and sampling bias. First, many Inrix, Inc. probe vehicles are heavier vehicles, which are lower than for other users. Moreover, during stop-start conditions (e.g. during congestion or on heavily signalized roadways) acceleration patterns of heavy vehicles would further slow probe vehicles down. These would lead Inrix, Inc. speed estimates to be slower on arterials and comparatively slower on freeways under congested conditions.

Second, insofar that the travel patterns of Inrix probes and heavy vehicles do not reflect broader travel patterns by the general motoring public, there is additional sampling bias. Thus, while freight system users are more likely to travel by freeway over longer distances, trips by members of the general public are not as long and freeway travel does not feature as prominently in comparison. As a result, one would expect freeways to be oversampled relative to arterials. Without adjusting for these sources of oversampling, metrics would be expected to overstate the role of freeways in reflecting broader transportation service conditions.

CIMA (2012) compared several data sources used to estimate traffic speeds, including Bluetooth technology, TomTom, and Inrix, Inc. Despite the above two potential sources of sampling error, CIMA (2012) concluded that the three data sources studied were largely indistinguishable in terms of accuracy or validity. Instead, the chief differentiating factor among the data sources was the geographic coverage within the network. Among the three, Inrix, Inc. had wider geographical coverage than the other sources. The full Inrix, Inc. dataset purchased for this study includes 1,911 links comprising 2,021 link-kilometers of roadways, of which 383 link-kilometers (19%) are freeways. These links represent freeway mainlines and major arterials within the network.

Although Inrix, Inc. provides transportation service estimates for all links in the study network for all time periods for which data are available, the temporal and spatial coverage of the data play a key role in determining the roadways and time periods included in this analysis. Both arterials and freeways are evaluated in 2014, when Inrix coverage was at its best, while only freeways are assessed in day-to-day analyses of 2011 and 2013 (see Figure 2). As shown in Figure 2, almost all sections of freeway are included within the City of Toronto, including the 400-series freeways (under Provincial management), the Gardiner Expressway (under City management), and the Don Valley Parkway (under City management). It is unclear why two sections of freeway (the southernmost sections of the 427 and the 404) have no available data. But based on discussions with Inrix, Inc. personnel, it appears that these approaches may be missing due to the idiosyncratic geometries of the TMC links near these major freeway-to-freeway interchanges.

Figure 1. City of Toronto Inrix, Inc. Data Coverage Map (2011-2014)

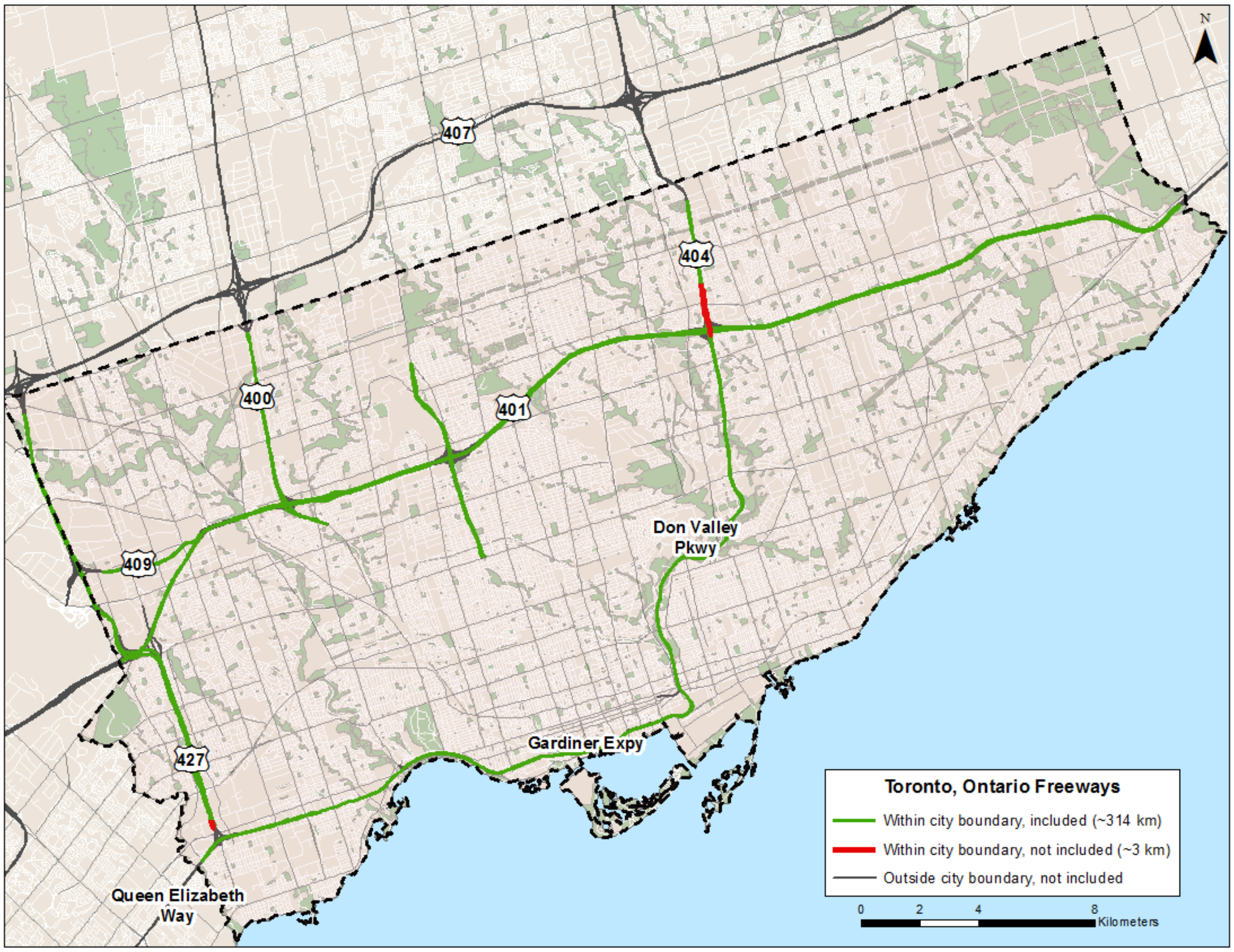

Figure 2. Freeway Sections Included in City of Toronto Study

The data quality of arterials and freeways are compared and shown in Table 1. This exploration illustrates that a) coverage is better for freeways than for arterials and b) coverage improves between 2011 and 2014 – particularly for arterials. Based on these improvements, the daily variations in road speeds are estimated for the freeway system in each of the study years and daily variations in road speeds are estimated for the arterial network exclusively for 2014, when coverage is best.

Table 1. Network Coverage by Inrix, Inc. Probes During 15-Minute Intervals (5am-10pm)

Network Type	Link-Km Coverage Share	Median Link-Km Coverage Share	5th Percentile Worst Share	95th Percentile Best Share
2011 (Aug. 8 - Dec. 31)				
Freeway Mainlines	85.4%	93.4%	53.1%	98.3%
Arterials	36.4%	32.2%	3.7%	71.8%
2013 (Jul. 1 - Dec. 31)				
Freeway Mainlines	88.6%	96.7%	56.1%	99.0%
Arterials	44.3%	42.3%	2.5%	83.7%
2014 (Jan. 1 - Dec. 31)				
Freeway Mainlines	88.7%	97.2%	58.5%	99.0%
Arterials	48.0%	50.1%	3.9%	88.0%

As one would expect based on a fleet of vehicles conducting longer trips, coverage on the freeways is much higher than on the arterials and the freeway network coverage has improved approximately 3.3% between 2011 and 2014. On average, coverage increased from 85.4% to 88.7% of time period-link kilometers covered on the freeway network between 2011 and 2014. For any specific hour in 2014, vehicles which are part of the Inrix, Inc. probe fleet cross 88.7% of the link-kilometers of freeway network, on average, during any given 15-minute intervals between 5am and 10pm. For any given 15-minute interval, the median share of link-kilometers covered on the freeway network is 97.2%, while for some 15-minute intervals, the frequency is lower. For example, in the 5^{th} percentile worst coverage 15-minute interval, the freeway coverage is 58.5%, while on the 95^{th} percentile best coverage 15-minute interval, the freeway coverage is over 99%. As shown in Figure 3, in 2014, most 15-minute intervals between 5am and 10pm during each of the 365 days [n = 24,820 = 365 days * 4 (quarters per hour) * 17 (hours per day)] are covered in excess of 90% on the freeway network. Frequencies are lower for 2011 and 2013 because data respectively only cover August 8-December 31 and July 1 – December 31.

In comparison with the freeway network, coverage on the arterials is lower in absolute terms but has improved significantly more between 2011 and 2014: an approximately 11.6% improvement. For any specific link-kilometer on the freeway network in 2014, vehicles which are part of the Inrix, Inc. probe fleet cross a given link in 48.0% of the link-kilometers of freeway network during any given 15-minute intervals between 5am and 10pm. Additional descriptive statistics are shown in Table 1 and Figure 4.

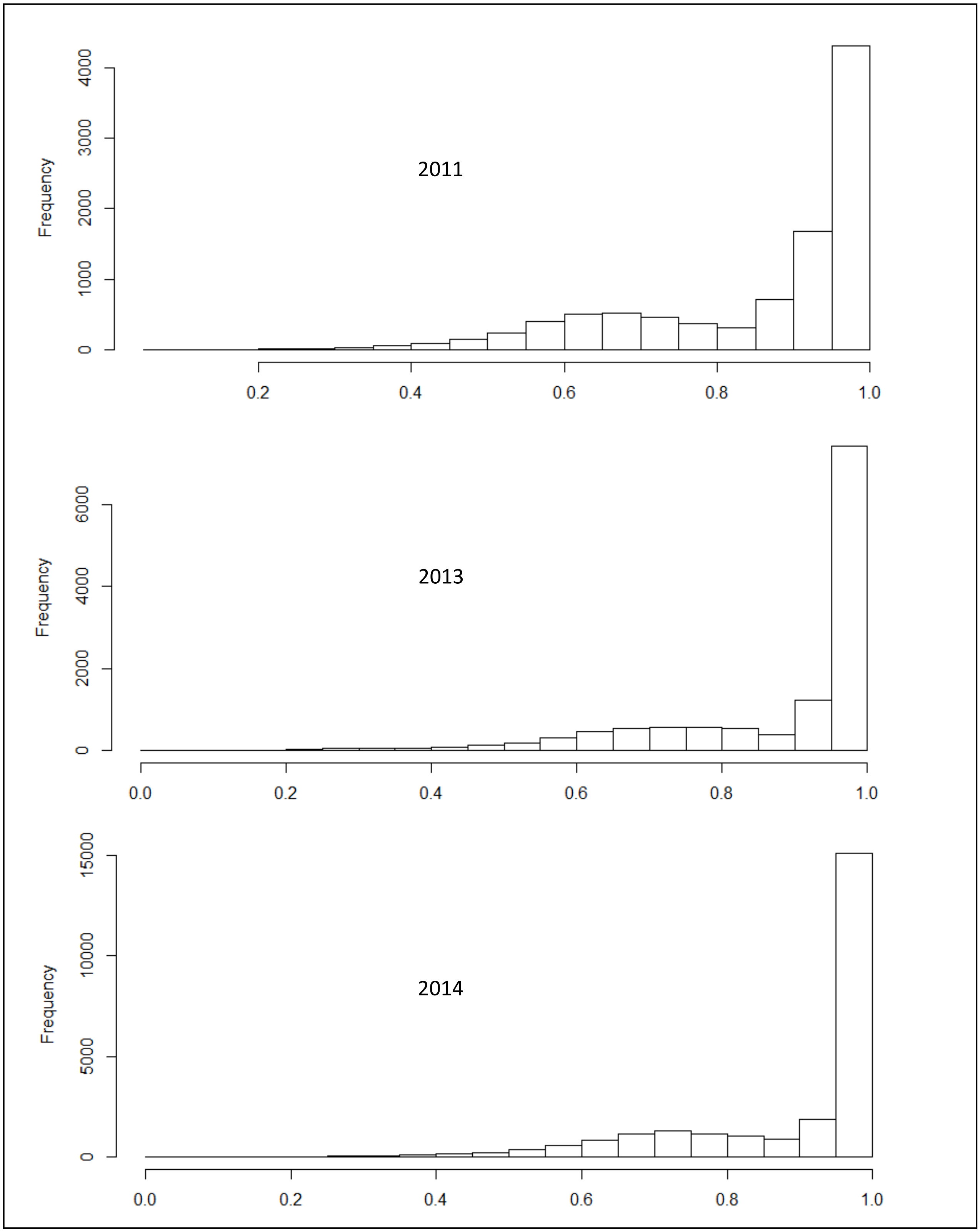

Figure 3. Freeway Coverage Share in 2011, 2013, and 2014: share of link-kilometers during each 15-minute interval between 5am and 10pm

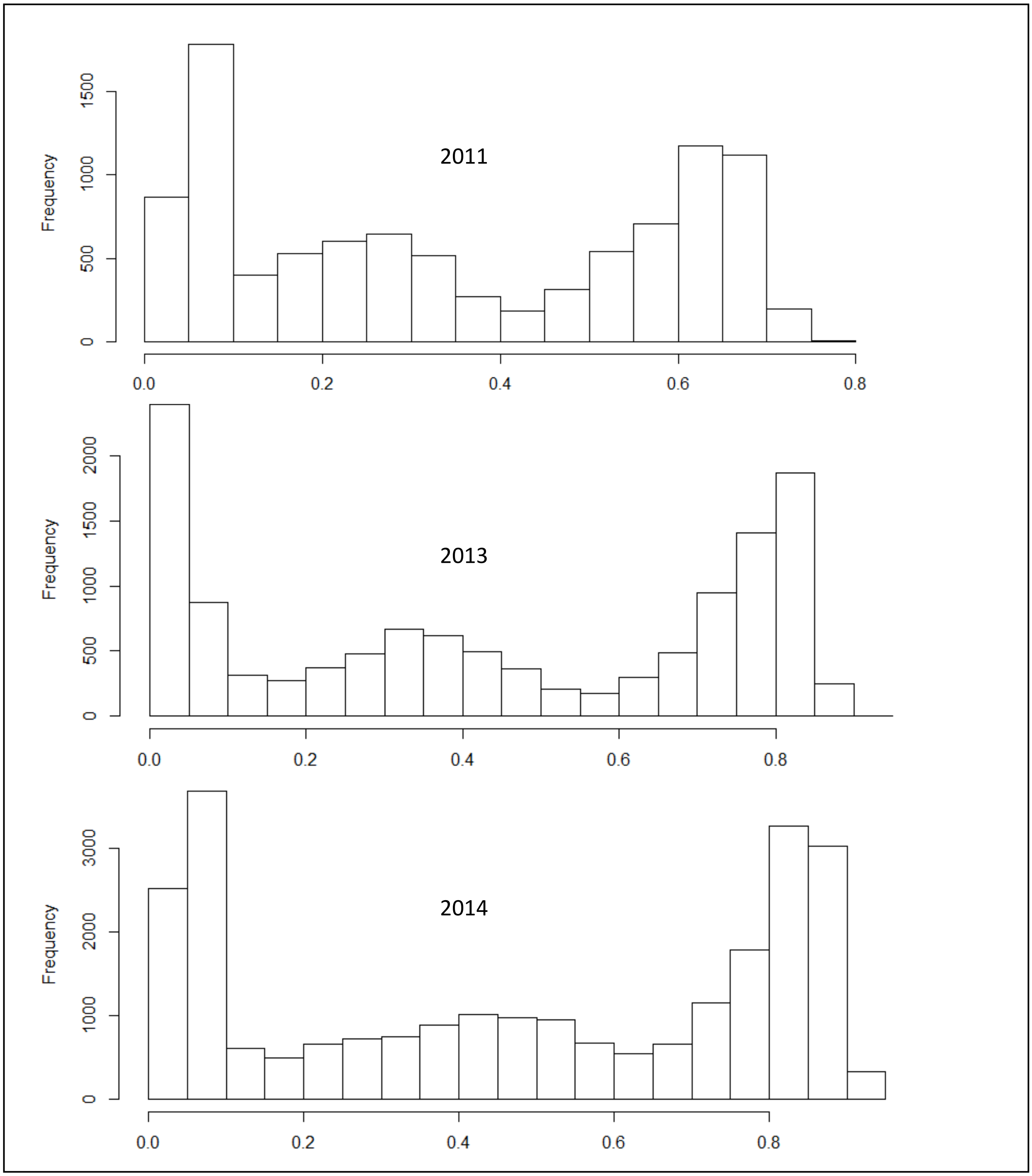

Figure 4. Arterial Network Coverage Share in 2011, 2013, and 2014: share of link-kilometers during each 15-minute interval between 5am and 10pm

2.1.3 Roadway Lengths

In addition to the link-specific service data collected from Inrix, Inc., data on road network characteristics are employed to gauge the extent to which each speed or service measurement influences the experiences of different system users. Chiefly, the metrics in this study depend on estimating vehicle volumes within the network, and these volumes are further weighted based on the link lengths to characterize the intensity of use on each link. A map of all arterial and freeway links included in the Inrix, Inc. dataset is displayed in Figure 1 and, of these, approximately 19 percent are freeways.

2.2 Metric Definition

Daily variations in transportation system performance are estimated by first focusing exclusively on the freeway system for all three years and then by focusing exclusively on the arterial system located within the City of Toronto municipal boundaries in 2014. Only one road transportation system performance measure is employed: travel speeds. Other metrics are ignored for the purposes of this analysis for three reasons. First, unreliability-based measures at the level of each day are not meaningful because individual days are the units of analysis. Second, travel time indices are directly related to observed speeds relative to free-flow conditions (which vary very little along the freeway network), thereby providing little additional information. Finally, although measures of net delay (e.g. in terms of millions of hours of vehicular delay) could be estimated, they depend on good measures of day-to-day variations in vehicular volumes – which cannot be reasonably accommodated by the existing data sources.

Although service attributes are available for each day within the study dataset, multilevel modeling is employed to estimate transportation service attributes in lieu of conventional descriptive statistics. This method is employed to avoid measurement issues related to the non-random nature of the Inrix, Inc. sample. It is impossible to know the “true” transportation service characteristics from which to estimate the extent or intensity of sample bias, but employing multilevel modeling enables targeted comparisons to be conducted at very fine granularities within the existing dataset. In this case, while the “true” service levels could be somewhat different than those shown, the data retains internal validity because variations in service quality across links or across time periods are maintained. Thus, while the “true” vehicle speeds are likely faster than those observed in the Inrix, Inc. dataset because many Inrix probes are heavy vehicles, this lack of representativeness is less material for the purposes of looking at differences between different days.

2.2.1 Descriptive Statistics

To illustrate why multilevel modeling is employed, first the conventional descriptive statistics are introduced as a means to identify the relative transportation service levels across different days.

Ignoring the relative weighting of links for the moment, for a simplified two-link network using two time periods, average daily vehicle speeds can be estimated as follows:

Equation 1. Simplified Un-weighted Descriptive Statistics

$$\bar{x} = \frac{P_{1a} + P_{2a} + P_{1b} + P_{2b}}{4},$$

where $\bar{x}$ represents the mean vehicle speed, P_{1a} represents the speed of link 1 at time period a, P_{2a} represents the speed of link 2 at time period a, P_{1b} represents the speed of link 1 at time period b, and P_{2b} represents the speed of link 2 at time period b.

However, as different links carry different vehicular volumes, weighting average speeds by volumes enables a potentially more representative measure of typical user experience on the given network. For example, if one link carries 100,000 vehicle-kilometers of traffic, while another carries only 1,000 vehicle-kilometers of traffic, weighting each equally would overstate the role of the second link in the fully network performance. Using the simplified example above, weighting can be accomplished as follows:

Equation 2. Simplified Weighted Descriptive Statistics

$$\bar{x} = \frac{P_{1a} * V_{1a} + P_{1b} * V_{1b} + P_{2a} * V_{2a} + P_{2b} * V_{2b}}{V_{1a} + V_{1b} + V_{2a} + V_{2b}} = \frac{\sum_{i=1}^{n} P_{it} * V_{it}}{\sum_{i=1}^{n} V_{it}},$$

where P_{1a} through P_{2b} are already defined; V_{1a} through V_{2b} represent the link and time-period specific volumes (in vehicle-kilometers of travel); and these are further simplified to P_{it} represents the vehicle speed on the link (denoted *i*) and time period of interest (denoted *t*); and V_{it} represents the vehicle volumes (in vehicle-kilometers of travel).

However, because the dataset in question is highly dependent on freight and commercial fleets, one may expect that the vehicles may travel on high (or low) congestion links on some days rather than others or travel during high (or low) congestion time periods on some days rather than others – leading to measurement error. Conceptually, Inrix, Inc. probe vehicles may travel on highly-congested links during peak periods on one day but on low-congestion links during off-peak periods on another day, so estimating whether one day is more congested than another depends on understanding the day-specific transportation system performance characteristics relative to one's expectations. Thus, speeds on the uncongested links during uncongested times may be lower than usual but higher than the speeds on highly-congested links during peak periods – erroneously giving a sense of fast service levels.

2.2.2 Multilevel Modeling

As used in this study, multilevel modeling can best be understood as an extension of regression which is employed to capture mean tendencies (Scott, Simonoff, & Marx, 2013; Gelman & Hill, 2007) for daily performance levels relative to expectations using a non-random sample. In the most basic model, mean vehicle speeds can be interpreted like the descriptive statistics above and estimated as follows:

Equation 3. Basic Model

$$y_i = \beta_0 + \varepsilon_i ,$$

where y_i represents the observed speed for a given freeway link during a time period within the year (each denoted *i*), β_0 represents the intercept, and ε_i represents the error term specific to observation *i*.

Because the model, estimated using maximum likelihood, estimates link-specific speeds simply as a function of a constant and an error term, the constant β_0 represents the expected speed in the absence of any additional information whatsoever about the link –the *mean speed*.

Equation 3 is expanded as a mean model, as described by Scott, Simonoff, and Marx (2013), to accommodate additional features of interest to identify daily variations in congestion, as follows:

Equation 4. Basic Day-Variant Model

$$y_{id} = \beta_{0d} + \varepsilon_{id} ,$$

where y_{id} represents the observed speed for a given link during a time period (each denoted *i*) which in turn are estimated for each day in the 365-day calendar year (denoted *d*), β_{0d} represents the intercept for each day in the calendar year, and ε_i represents the error term specific to observation *i*.

In the case of Equation 4, the model would estimate a total of 365 coefficients – one for each day of the year and these would describe mean speeds on each of the days in the course of the year. However, given that it cannot be verified whether Inrix probe data overestimates congestion on particular days over others (due to non-random sampling across links or across time periods), an additional set of controls are needed to estimate unbiased daily means as follows:

Equation 5. Day-Variant Model

$$y_{itd} = \beta_{0d} + \beta_{2it} + \varepsilon_{itd} ,$$

where y_{itd} represents the observed speed for a given link during a time period (each denoted *i*) for each day in the 365-day calendar year (denoted *d*) for each of the 17 hours in the day, β_{0d} represents the intercept for each day in the calendar year, β_{2it} represents the intercept for each link at each time period within the day; and ε_i represents the error term specific to observation *i* at time *t* on day *d*.

Thus, up to 365 coefficients are being estimated for β_{0d}, each representing the mean unbiased freeway speeds in the network, and (in the case of the freeway models) more than 6,766 unique coefficients are estimated for β_{2it} (398 unique links * 17 hours in the day). The coefficient estimates for β_{2it} are only of secondary interest and are designed to establish an expectation from which the mean daily congestion levels can vary. As such, even if a given day only has sampled speeds on less congested links at off-peak time periods while another has sampled speeds for more congested speeds during peak time periods, the speeds on each of these sets of links and time periods are compared to the expected means for those links to establish whether the daily mean is higher or lower than expected. Models are estimated using the lme4 package with the software R.

2.2.3 Weighting by Counts

While the multilevel model can better estimate unbiased average daily freeway speed estimates, as described above, additional weighting is necessary to more heavily weight long freeway links with high volumes than shorter freeway links with lower volumes. To accomplish this, a weighting scheme is designed using the normalized product of the link-specific lengths and their hourly volume estimates generated using MITL'S internal four-step modeling package, TRAFFIC. These weights are estimated as follows

$$w_{it} = \frac{V_{it}L_i}{\sum_{i=1}^{n} V_{it}L_i \Big/ 17n},$$

Where w_{it} represents the weight for link *i* at time period *t*; V_{it} represents the estimated volume for link *i* at time *t* (from the four-step travel demand model, TRAFFIC) and L_i represents the length of link *i*; and $\sum_{i=1}^{n} V_{it}L_i \Big/ 17n$ represents the mean volume (in vehicle-kilometers of travel) across the system (*n* being the number of links and 17 being the number of hours analyzed in the day). As such, the weight has a mean value of 1 if the vehicle kilometers of travel are equal to the mean across the system and values are higher or lower depending on the level of travel intensity.

2.3 Model Modifications

While the final multilevel model (Equation 5) captures day-to-day variations in traffic congestion, the model is computationally infeasible when expanded to an entire year of data for specific hourly intervals across the entire freeway network in the City of Toronto. Data include more than 2.4 billion potential hourly observations annually on the freeway network alone (=392 links * 17 hours per day * 365 days per year). As such, models are estimated separately for each month to identify key variations, leading months to not be perfectly comparable to one another. To identify the final set of slowest performing days and fastest performing days, days are selected based on the month-specific models and pooled to compare directly to one another.

3

Results

Using multilevel modeling, Inrix, Inc. data is employed to identify the fastest and slowest days across the freeway network within the City of Toronto in 2011 (August 8-December 31), 2013 (July 1-December 31) and 2014 (January 1 – December 31), and across the arterial network within the City of Toronto for 2014. Results for each of the years are sequentially described, but each indicates several key findings. First, weather events play a key role in explaining the majority of the very slowest mean daily speeds in each of the three years. But while snow events featured prominently in explaining extremely slow days in 2013 and 2014, August 8 – December 31, 2011 was relatively mild, so rain events were the most important explanations of the very slowest daily mean speeds observed during this period of 2011. Second, in a majority of the cases, the fastest mean daily speeds of each of the study years can be explained by statutory holidays on which little commuting and travel took place. Third, differences in weekdays and weekends are clear across all study years and when focusing exclusively on the arterial network (2014) or freeway network (2011-2014). Finally, the greatest day-to-day uncertainty in travel speeds occurs in the winter, when major weather events (which slow speeds) and holidays (which are associated with faster speeds) conspire to introduce much more variation in transportation system performance.

3.1 2011 (August 8-December 31) Results

Model results for 2011 are estimated independently for each month and displayed in Figure 5 (labeled 8 for August through 12 for December). Trend lines and bands (two standard deviations of the observations in question) are shown to independently illustrate the temporal trends in mean daily freeway speeds between weekends (blue) and weekdays (red). On average, weekend speeds are 8.7 kph faster than weekday speeds. Mean daily freeway speeds range between approximately 83 kph and 104 kph. Beyond differences between weekdays and weekends, Figure 5 illustrates general trends whereby broader patterns in congestion appear evident from week to week. For example, mean weekday speeds appear to increase in August before they generally decline beginning in September (when school is back in in session). Then in December, both weekday and weekend speeds appear to increase in the course of the month as the Christmas holidays come closer – with the exceptions of some slow days on which weather events occurred. Between August 8, 2011 and December 31, 2011, Saturdays are slower than Sundays, while weekday patterns are less clear.

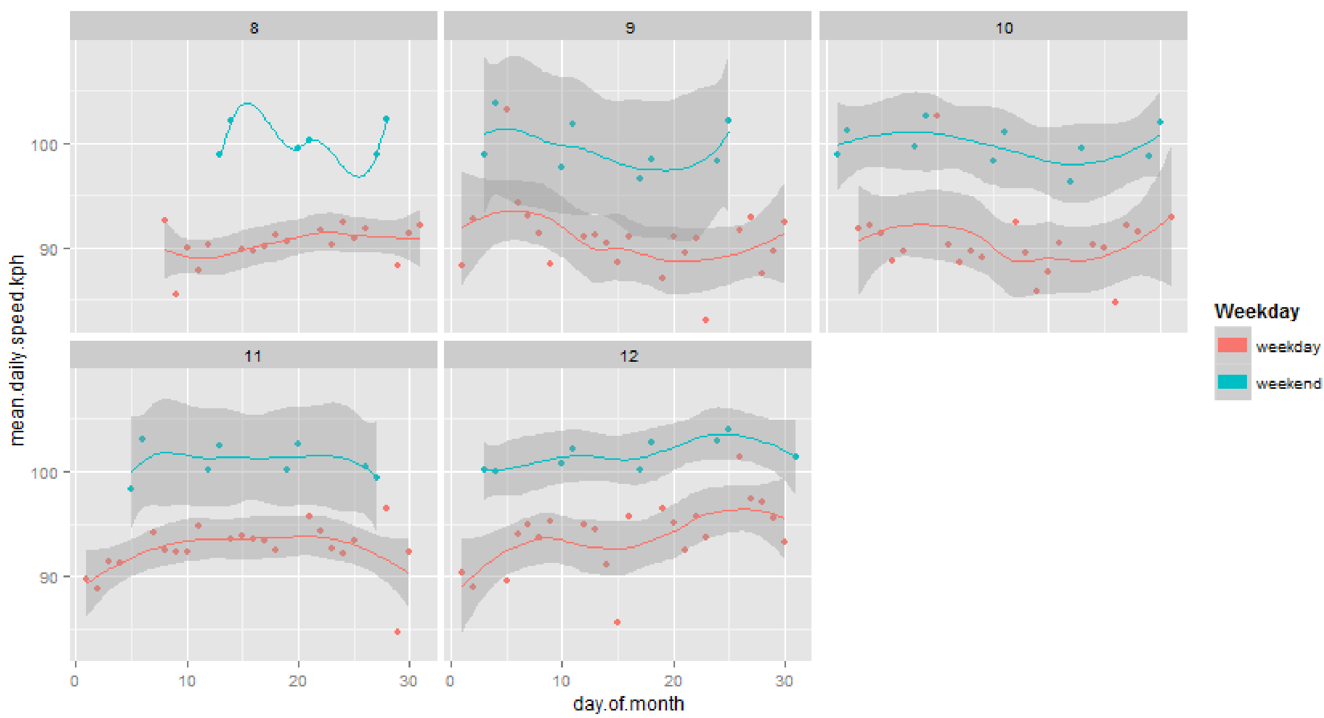

Figure 5. Mean Daily Freeway Speed (kph) by Month and Day in 2011 (Aug. 8-Dec. 31)

Independent multilevel models are estimated, respectively, for 27 of the candidate "fastest" and 22 of the candidate "slowest" days of the year to directly compare the most extreme days, providing evidence on the rank order and point estimates of freeway speeds aggregated to daily levels. Nine of the ten slowest days of the year (only focusing on August 8-December 31) had rain events ranging from 4.2 mm (September 28) to 48.8 mm (October 25); there was no major snow event during this study period as it was a relatively mild.

Table 2. Slowest Mean Daily Freeway Speeds of 2011 (Aug 8-Dec 31)

Rank	Date	Weekday	Weather	Events	Speed (kph)
1	Sep 23	Friday	22.2mm of rain, foggy and cloudy conditions all day	Rain	83.7
2	Oct 26	Wednesday	6.2mm of rain, drizzle all day, fog majority of day	Rain	85.6
3	Nov 29	Tuesday	48.8mm of rain, rain all day, some evening fog	Rain	85.6
4	Aug 9	Tuesday	13.8mm of rain, foggy and cloudy conditions midday	Rain	85.7
5	Oct 19	Wednesday	34.2mm of rain, rain most of the day, fog in the evening	Rain	86.6
6	Dec 15	Thursday	7.4mm of rain, foggy conditions	Rain	86.8
7	Sep 19	Monday	12.8mm of rain, foggy conditions all afternoon	Rain	87.7
8	Aug 11	Thursday	no precipitation		88.0
9	Sep 28	Wednesday	4.2mm of rain in the early morning and mid afternoon	Rain	88.0
10	Oct 20	Thursday	16.6mm of rain, fog early morning	Rain	88.4

Next the fastest days within August 8 to December 31, 2011 are compared, indicating that six of the 11 fastest days of the study period were holidays. Among the other five days on which the mean daily freeway speeds were among the 11 fastest in the year, all were in either November or December.

Table 3. Fastest Mean Daily Freeway Speeds of 2011 (Aug 8-Dec 31)

Rank	Date	Weekday	Weather	Events	Speed (kph)
1	Dec 25	Sunday	no precipitation	Christmas Day	103.0
2	Sep 4	Sunday	3.4mm of rain	Labour Day Long Weekend	102.3
3	Dec 24	Saturday	no precipitation	Christmas Eve	102.0
4	Dec 18	Sunday	no precipitation		101.9
5	Sep 5	Monday	no precipitation	Labour Day	101.7
6	Nov 6	Sunday	no precipitation		101.6
7	Nov 13	Sunday	no precipitation		101.4
8	Oct 10	Monday	no precipitation	Thanksgiving Monday	101.3
9	Nov 20	Sunday	no precipitation		101.3
10	Oct 9	Sunday	no precipitation	Thanksgiving Long Weekend	101.1
11	Dec 11	Sunday	no precipitation		101.1

3.2 2013 (July 1-December 31) Results

Model results for 2013 are likewise estimated independently for each month and displayed in Figure 6. Weekend speeds are on average 7.2 kph faster than weekday speeds and the single month with the largest day-to-day variations in freeway speeds is December – largely as a consequence of severe weather events (during which speeds are slow) and statutory holidays (during which speeds are fast).

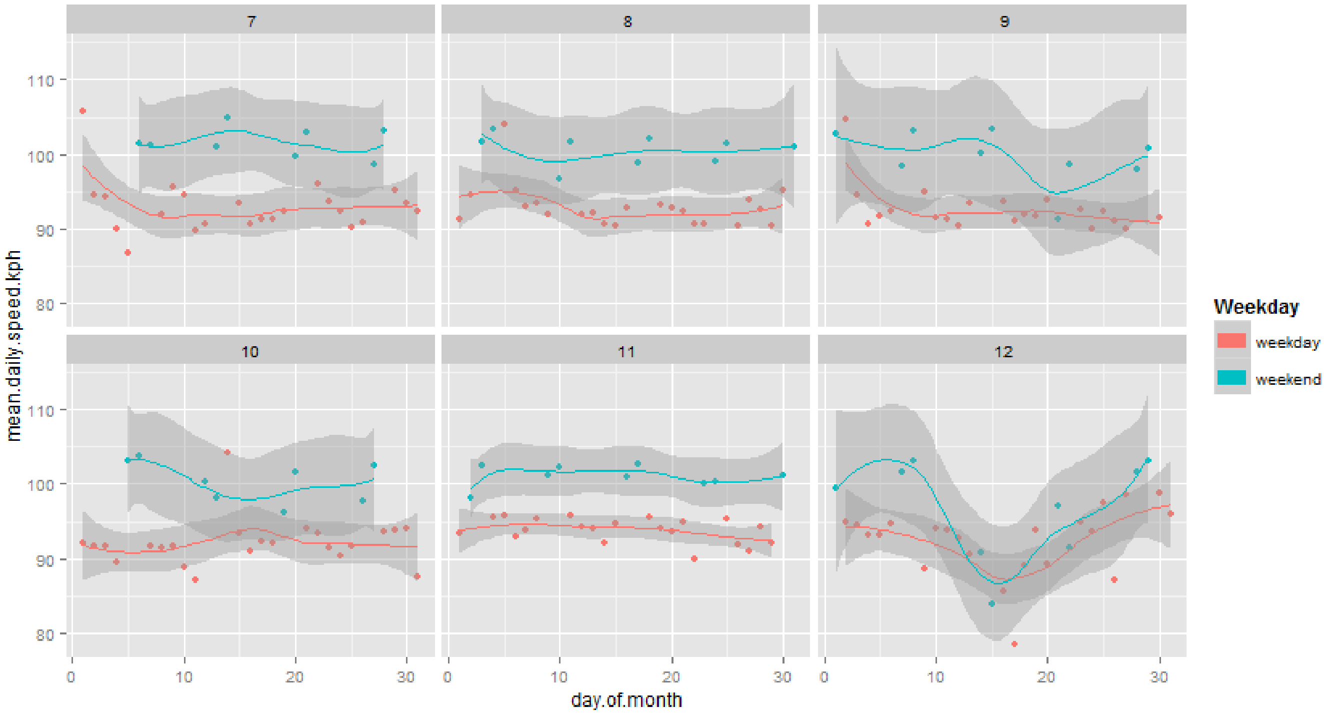

Figure 6. Mean Daily Freeway Speed (kph) by Month and Day in 2013 (July 1-Dec. 31)

Among 28 of the slowest days and 22 of the fastest days, independent models are estimated to directly compare speeds and identify the slowest and fastest days of the year, shown in

Table 4 and Table 5. As shown in

Table 4, half of the slowest days of July 1-December 31, 2013 are a function of major weather events. Of the ten slowest days, five include snow (including Boxing Day), and one is Halloween.

Table 4. Lowest Mean Daily Freeway Speeds of 2013 (July 1-Dec 31)

Order	Date	Weekday	Weather	Events	Speed (kph)
1	Dec 17	Tuesday	2.6cm of snow, 11cm of snow on the ground, <31km/hr wind, snow showers most of the day	extreme cold weather alert issued for Toronto	79.3
2	Dec 15	Sunday	3cm of snow, 12cm of snow on the ground, 59km/hr wind, blowing snow in early morning and later in evening	Toronto's first heavy snowstorm of the season, lots of car accidents reported	84.8
3	Dec 16	Monday	0.2cm of snow, 12cm of snow on the ground, <31km/hr wind	first day back to work after big snow storm	86.5
4	Jul 5	Friday	not recorded		86.7
5	Oct 11	Friday	no precipitation	Friday before Thanksgiving	87.4
6	Oct 31	Thursday	not recorded	Halloween	87.8
7	Dec 26	Thursday	3.4cm of snow, 9cm of snow on the ground, 46km/hr wind, blowing snow conditions in the afternoon	Boxing Day	87.9
8	Oct 10	Thursday	no precipitation		89.2
9	Dec 9	Monday	1.4cm of snow, 1cm of snow on the ground, 70km/hr wind		89.5
10	Jul 11	Thursday	no precipitation		89.7

As shown in Table 5, four of the ten fastest days of July 1-December 31, 2013 are statutory holidays. However, the rank order or difference between these "fast" days and other relatively fast days should not be overstated in terms of their meaning to system users: there is only a mean daily difference of 2.1 kph between the fastest and tenth fastest days of the year.

Table 5. Highest Mean Daily Freeway Speeds of 2013

Rank	Date	Weekday	Weather	Events	Speed (kph)
1	Jul 1	Monday	no precipitation	Canada Day	103.9
2	Jul 14	Sunday	no precipitation		103.1
3	Sep 2	Monday	no precipitation	Labour Day	103.0
4	Oct 14	Monday	no precipitation	Thanksgiving Monday	102.6
5	Dec 8	Sunday	no precipitation		102.3
6	Aug 5	Monday	no precipitation	Civic Holiday	102.3
7	Oct 6	Sunday	1.6mm of rain early morning, fog conditions most of the day	Rain	102.3
8	Dec 29	Sunday	4cm of snow on the ground		102.2
9	Oct 5	Saturday	2.2mm of rain	Rain	101.8
10	Nov 17	Sunday	12.4mm of rain in the morning and evening	Rain	101.8
11	Sep 15	Sunday	1.8mm of rain	Rain	101.8

3.3 2014

Daily mean speeds are estimated for the full calendar year of 2014 and models are estimated separately for the freeway network and the arterial network within the city boundaries, each is discussed and presented in turn. Like the partial year results from 2011 and 2013, 2014 results indicate that the largest day-to-day variations in freeway speeds occur in the winter months. As shown in Figure 7, freeway speeds are largely stable between weekdays and weekends: weekdays are approximately 8.0 kph slower than weekends, on average across the year. Between May (month 5) and August (month 8) mean daily freeway speeds vary only moderately between weekday and weekends, but day to day variations are much more pronounced in fall and winter months when there is extreme weather. As in previous years, Saturdays are slower than Sundays, while (particularly during summer months) freeway system speeds appear to decline over the course of the five weekdays and bottom out on Thursday.

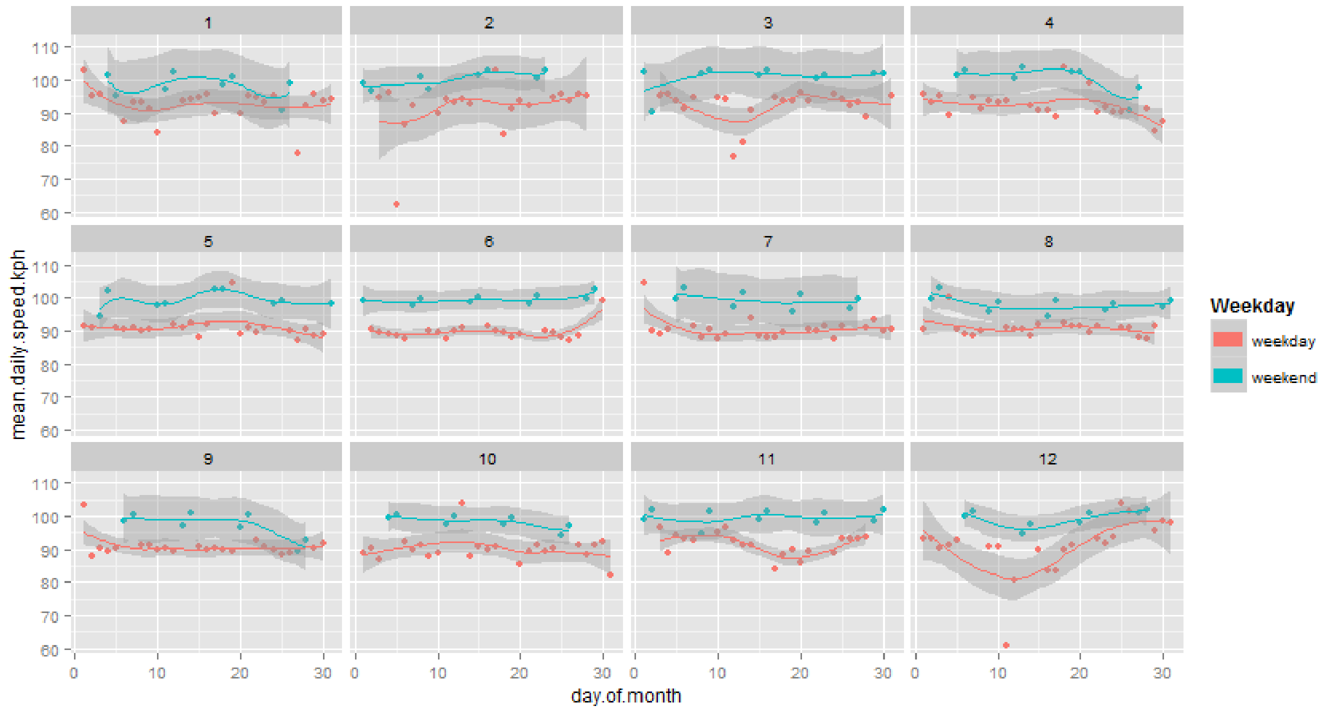

Figure 7. Mean Daily Freeway Speed (kph) by Month and Day in 2014

Independent multilevel models are estimated, respectively, for 30 of the "fastest" and 40 of the "slowest" days of the year to directly compare the most extreme days and provide evidence on the rank order and point estimates of freeway speeds aggregated to daily levels. These 30 and 40 days, respectively, are manually selected based on their speed estimates as potential days which are among the ten fastest or ten slowest.

The fourteen days on which the mean freeway speeds were slowest during the calendar year 2014 include 11 days on which snow played a role, two days of rain (including Halloween), and the first Tuesday after the Gardiner Expressway was closed for major construction. Only the fourteen slowest days are displayed based on logical thresholds and not a single of these days is a weekend. As described in Table 6, the days with the slowest mean freeway speeds can be linked with weather events matched against Government of Canada climate data for Pearson International Airport (Government of Canada, 2015). The two slowest days, each of which were extreme snow events, had average daily freeway speeds under 65 kilometers per hour (61.6 and 63.3 kph) – indicating that across all hours between 5am and 10pm, freeways were functioning at approximately half their normal speeds. The slowest weekend days of the year include Saturday, September 27th (89.3kph), Sunday, March 2 (91.1 kph and snow); April 26 (91.5 kph and the first day of Gardiner maintenance/closure); and January 25th (92.5 kph and snow), but even the slowest of these is only in the top 30 slowest days of the year.

Table 6. Lowest Mean Daily Freeway Speeds of 2014

Rank	Date	Weekday	Weather	Events	Speed (kph)
1	Dec 11	Thursday	17.4cm of snow, 4cm on the ground, fog conditions	Snow	61.6
2	Feb 05	Wednesday	14.9cm of snow, 15cm on the ground, heavy and blowing snow throughout the day	Snow	63.3
3	Mar 12	Wednesday	9.2cm of snow, 1cm on the ground, blowing snow in the evening and continuing into the next morning	Snow	77.5
4	Jan 27	Monday	2.4cm of blowing snow, 9cm of snow on the ground	Snow	77.7
5	Dec 12	Friday	no new snow, but 17cm on the ground from the previous day	Previous Night Snow	81.6
6	Mar 13	Thursday	blowing snow in the morning, 8cm of snow on the ground	Snow	82.1
7	Oct 31	Friday	10.8mm of rain	Halloween	82.2
8	Jan 10	Friday	1.8cm of snow, but 10cm of snow on the ground. Foggy conditions from 10am-8pm	Snow	84.3
9	Dec 17	Wednesday	1.8cm of snow, mix of snow and rain	Snow	84.3
10	Nov 17	Monday	6.3cm of snow, 5cm on the ground, some fog conditions from 3-5pm	Snow	84.8
11	Feb 18	Tuesday	4.4cm of snow, 20cm on ground, blowing snow for most of the day	Snow	85.0
12	Apr 29	Tuesday	cloudy conditions, no precipitation	Tuesday after closing Gardiner	85.0
13	Oct 20	Monday	6.4mm of rain, foggy conditions	Rain	85.5
14	Nov 20	Thursday	blowing snow between 5am and 1pm	Snow	86.4

The days of the year on which mean daily freeway speeds were highest, in contrast, were primarily statutory holidays. Of the sixteen fastest days of the year, 11 are holidays. But while clear differences are evident in the point estimates of average daily freeway speeds among the fourteen slowest days, the speed differences among the 16 fastest days are small. The single fastest day of the year is only 2.1 kph faster than the 16^{th} fastest. While such a difference is technically statistically significant based on the large sample sizes in this study, these differences should not be overstated in terms of their meaning.

Table 7. Highest Mean Daily Freeway Speeds of 2014

Rank	Date	Weekday	Weather	Events	Speed (kph)
1	Jul 1	Tuesday	6.6mm of rain, 50km/hr wind	Canada Day	103.1
2	May 19	Monday	no rain, 43km/hr wind	Victoria Day	102.9
3	Dec 25	Thursday	no precipitation, 80km/hr wind	Christmas Day	102.9
4	Jan 1	Wednesday	no precipitation, 3cm of snow on ground, 35km/hr wind	New Year's Day	102.7
5	Jan 12	Sunday	no precipitation, 4cm of snow on ground, 59km/hr wind		102.6
6	Apr 18	Friday	0.4mm of rain, 41km/hr wind	Good Friday	102.4
7	Feb 16	Sunday	0.4cm of snow, 15cm of snow on ground, 39km/hr wind		102.4
8	Apr 13	Sunday	6mm of rain, 61km/hr wind		102.4
9	Feb 23	Sunday	no precipitation, 7cm of snow on ground, 57km/hr wind		102.2
10	Feb 17	Monday	1.2cm of snow, 16cm of snow on ground, 59km/hr wind		102.2
11	Oct 13	Monday	no precipitation, <31km/hr wind	Thanksgiving Monday	101.9
12	Sep 1	Monday	2.8mm of rain, 46km/hr wind	Labour Day	101.7
13	Aug 3	Sunday	no precipitation, <31km/hr wind	Civic Holiday Long Weekend	101.3
14	Jun 29	Sunday	0.4mm of rain, 44km/hr wind	Canada Day Long Weekend	101.1
15	May 17	Saturday	no precipitation, 41km/h wind	Victoria Day Long Weekend	101.1
16	May 18	Sunday	1.4mm of rain, 35km/hr wind	Victoria Day Long Weekend	101.0

Finally, mean arterial speeds are estimated across the year for 2014 and results are very similar to the freeway analysis above, with some exceptions. As expected, speeds are much lower, ranging from approximately 35 to 50 kph. These speeds include all movement along links, including signalization, so are broader indicators of system performance than simply mainline speed checks. As with the freeway analysis, similar severe days emerge, but some patterns are different. For example, while the greatest day-to-day variation is still in the winter and Saturdays are still slower than Sundays, Fridays appear to be the slowest day of the week on the arterial system while Thursdays generally are the slowest days of the week on the freeway system – particularly in the summer.

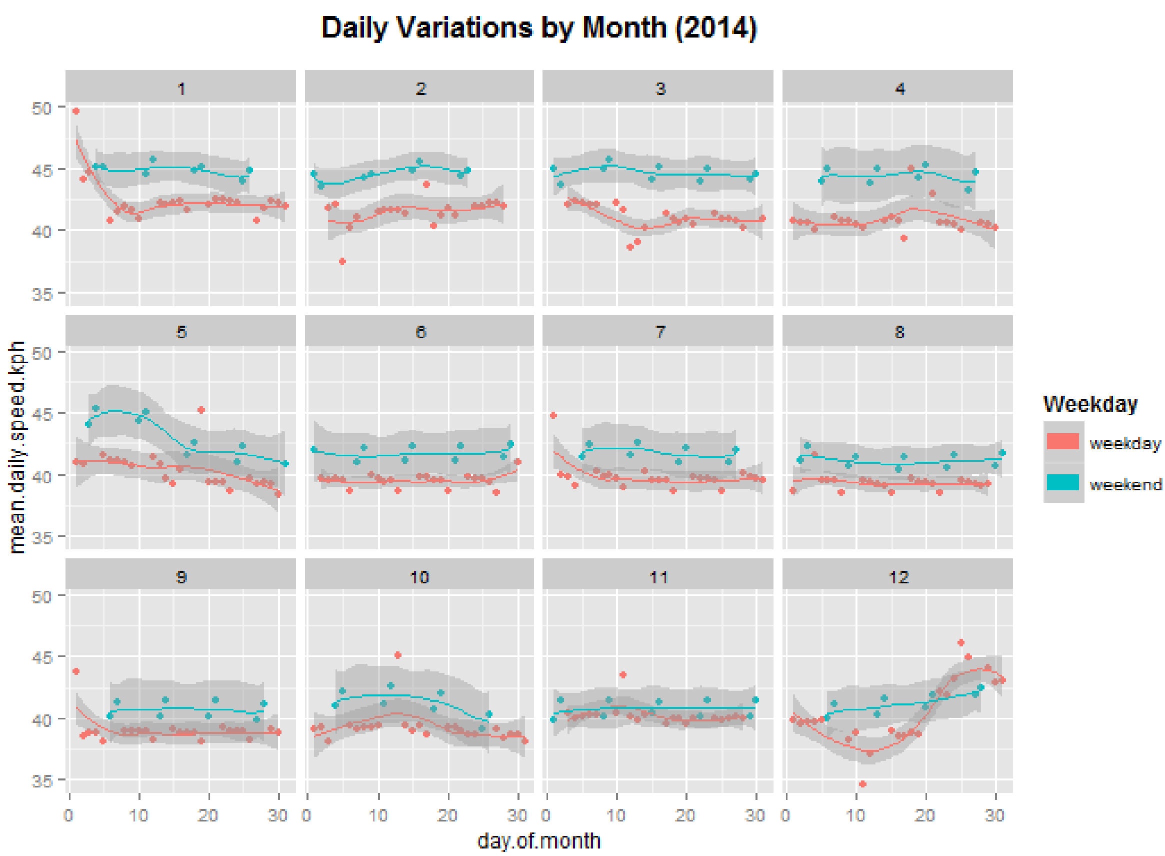

Figure 8. Mean Daily Arterial Speed (kph) by Month and Day in 2014

Independent multilevel models are estimated for the arterial system in 2014, respectively, for 47 of the "slowest" and 40 of the "fastest" days of the year to directly compare the most extreme days and provide evidence on the rank order and point estimates of freeway speeds aggregated to daily levels.

As shown in Table 8, weather events played a role in eight of the 10 slowest arterial days (one of which was Halloween), while one of the other slowest days appears to be the first warm Friday of the calendar year (May 30). All ten of the slowest days are between Tuesday and Friday.

Table 8. Lowest Mean Daily Arterial Speeds of 2014

Rank	Date	Weekday	Weather	Events	Speed (kph)
1	Dec 11	Thursday	17.4cm of snow, 4cm on the ground, fog conditions	Snow	33.9
2	Dec 12	Friday	no new snow, but 17cm on the ground from the previous day	Previous-Night Snow	36.5
3	Oct 31	Friday	10.8mm of rain	Halloween	37.5
4	Dec 9	Tuesday	0.8 mm of rain	Light Rain	37.6
5	Dec 17	Wednesday	1.8cm of snow, mix of snow and rain conditions	Snow	37.9
6	Dec 10	Wednesday	No precipitation		38.1
7	Sep 2	Tuesday	14 cm of rain	Rain on 1st weekday after Labour Day	38.3
8	Feb 5	Wednesday	14.9 cm of snow	Snow	38.4
9	May 30	Friday	Warmest Friday to that point in 2014: High 25.4, Low 10.8; No Precipitation	First Warm Friday	38.4
10	Nov 20	Thursday	blowing snow between 5am and 1pm	Snow	38.4

Upon combining 40 of the fastest days of the years on the arterial system in a multilevel model to compare them directly, the single fastest day of the year was identified as January 1 (exceeding any other day by approximately 3.5 kph). The nine next fastest days were all weekend days between January and April, before the Gardiner Expressway rehabilitation began: January 4, January 5, January 12, February 16, February 23, March 9, March 16, and April 20. Mean speeds are relatively similar on each of these nine days: differences are at most 0.6 kph, so they are not shown in a table.

4

Conclusions

While transportation system users, businesses, residents, and policymakers strive to alleviate congestion in order to improve life quality, advance social priorities, or improve economic outcomes, road transportation system performance is a function of both effective program management and a function of factors which are external to policy and planning. This study employs link-specific and time-specific road transportation performance data in an effort to identify typical performance levels for specific days in 2011 (August 8-December 31), 2013 (July 1 – December 31) and 2014 (January 1 – December 31) within the City of Toronto – focusing on freeway system performance in all three years and arterial system performance in 2014.

Results indicate that the largest day-to-day variations in road transportation system performance are a function of factors which are largely external to the tasks of effective program management and policymaking: weather, statutory holidays, days of the week (weekdays vs. weekends), and seasonality. Insofar that policymakers can manage transportation user responses in light of the above four factors, significant benefits can accrue. The presence of these factors cannot be influenced by policymaking, but these findings imply that large benefits can be produced from managing the temporally-constrained peak demands of travel on weekdays, preparing users and assets for major weather events, and providing information to system users during key periods – most notably during winter months when there are the largest swings between low-speed days (e.g. during weather events) and high-speed days (e.g. on or adjacent to holidays). Differences between arterial system performance and freeway system performance indicate that there may be different roles in managing these systems and the external forces which influence system performance on each. For example, while Thursdays appear to be slowest on the freeway system (particularly in summer), Fridays are generally slowest on the arterial system.

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